# BULLETIN

of the
**Operations Research**
**Society of America**

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NATIONAL MEETING

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# Operations Research Society of America

1966-1967

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System Development Corporation
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P. O. Box 218
Yorktown Heights, N.Y. 10598

Herbert K. Weiss
Data Systems Division
Litton Industries
8000 Woodley
Van Nuys, California 91406

1966-69 Walter L. Deemer
Arms Control and Disarmament Agency
Weapons Evaluation & Control
New State Department Bldg.
Washington, D. C. 20451

George E. Nicholson, Jr.
Department of Statistics
University of North Carolina
Chapel Hill, North Carolina 27515

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## EDITORS OF ORSA PUBLICATIONS

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Monterey, California 93940

*Representatives to the AAAS*

W. Edward Cushen
National Bureau of Standards
U. S. Department of Commerce
Washington, D. C. 20234

Ellis A. Johnson
4819 Essex Avenue
Chevy Chase, Maryland 20015

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## BUSINESS OFFICE

Requests for membership information and applications as well as subscriptions and orders for back issues of *Society* publications should be addressed to:

**Operations Research Society of America**
**428 East Preston Street**
**Baltimore, Maryland 21202**

# BULLETIN

## OF THE

## *Operations Research Society of America*

**Supplement 1** **OPERATIONS RESEARCH** **Volume 15, 1967**

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# The New York Meeting

## REGISTRATION INFORMATION

### Registration

The registration desk will be located on the second floor of the New York Hilton Hotel and will be open:

| | |
|---|---|
| Tuesday, May 30 | 6:00 PM – 1:00 AM |
| Wednesday, May 31 | 8:00 AM – 5:00 PM |
| Thursday, June 1 | 8:15 AM – 4:30 PM |
| Friday, June 2 | 8:30 AM – 2:00 PM |

Persons who have prepaid the registration fee and for special events can pick up their material at the registration desk. The fees are:

| | |
|---|---|
| Registration, ORSA Member | $15.00 |
| Registration, ORSA Nonmember | $20.00* |
| Registration, Full Time Student | $3.00 |
| Luncheon, Wednesday | $5.00 |
| Banquet | $9.00 |
| Luncheon, Friday | $5.00 |

There will be a no-host Cocktail Party preceding the Banquet on Thursday evening. Except for a few designated guests and non-member invited speakers, all attendees are expected to register and pay the established fees. This includes speakers, panel members, and session chairmen.

### Preregistration

*Preregistration is strongly encouraged.* Prepayment for the Wednesday Luncheon is especially important, since a guarantee of the number of places must be made the previous day. A form for advance payment is enclosed. Please pay only by check or money order (made out to ORSA 31st National Meeting) to H. David Grace, *31st ORSA Meeting, Celanese Corporation, 522 Fifth Avenue, New York, New York 10024.*

### Accommodations

The New York Hilton Hotel has blocked off 300 rooms for this meeting. The daily rates for these rooms are: Single $12.00–16.00; Double $16.00–19.00; Twin $19.00–22.00; Studio $22.00–32.00; and Suites $46.00 up. A form for hotel rese tions is enclosed.

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* A non-member wishing to apply for membership when registering may hav of this fee credited toward his annual dues payment of $12.50.

## COMMENTS ON PROGRAM

The annual meeting is returning to the business capital of the country after seven years. During these years we have witnessed a steady increase of OR applications in the business and financial world. Significant contributions have been made in Production Management Systems, Marketing and Advertising. Corporate Management has been aided by the appearance of sophisticated Management Information Systems, some involving the use of on-line computers. All these applications are emphasized in the invited sessions of this meeting. In addition, there are invited sessions on new OR applications, as in Medicine and Hospitals, Environment Control, old and new Non-Military Government applications, and on new Analytical Techniques. All three Technical Sections of ORSA are also sponsoring sessions of invited papers. In addition, we received about one hundred contributed papers covering an equally wide spectrum of applications.

## WOMEN'S EVENTS

NEW YORK is happy to welcome the women of ORSA to this convention. Our women's committee will do everything possible to assist and entertain you.

| | |
|---|---|
| WEDNESDAY—*May 31* | |
| 9:00–11:00 A.M. | Coffee and information—Women's Hospitality Suite |
| 11:30 A.M.(*) | Luncheon, *United Nations Delegates' Dining Room.* Meet at the United Nations Information Desk, Secretariat Building, 42nd Street and First Avenue. |
| 1:00 P.M. (*) | Tour of the *United Nations* |
| THURSDAY—*June 1* | |
| 9:00–11:00 A.M. | Coffee and information—Women's Hospitality Suite |
| 11:00 A.M. (*) | Tour of *Lincoln Center for the Performing Arts.* Meet inside Philharmonic Hall, Broadway and 65th Street. |
| 12:30 P.M. (*) | Luncheon at Lincoln Center's *Top of the Met* in the new Metropolitan Opera House. |
| 6:00 P.M. | Cocktail Party and Banquet for delegates and wives at the New York Hilton Hotel. |
| FRIDAY—*June 2* | |
| 9:00–11:00 A.M. | Coffee and information—Women's Hospitality Suite. |

Reservations for the starred (*) events should be made by May 15th. Please use the enclosed "Women's Events" form and send it to MRS. GEORGE FEENEY, *51 Barrow Street, New York, New York 10014.*

*Theater Tickets:* A broker's order form is included for your convenience.

## COPIES OF PAPERS

Requests for copies of papers, also for information about the papers, should be e directly to the authors. Their addresses are contained in the statement of affiliation. Please do not contact any of the committee for the meeting, the on chairmen, or the Editor of *The Bulletin* about the papers that are prested. Also, panel members should be contacted directly about their discussions.

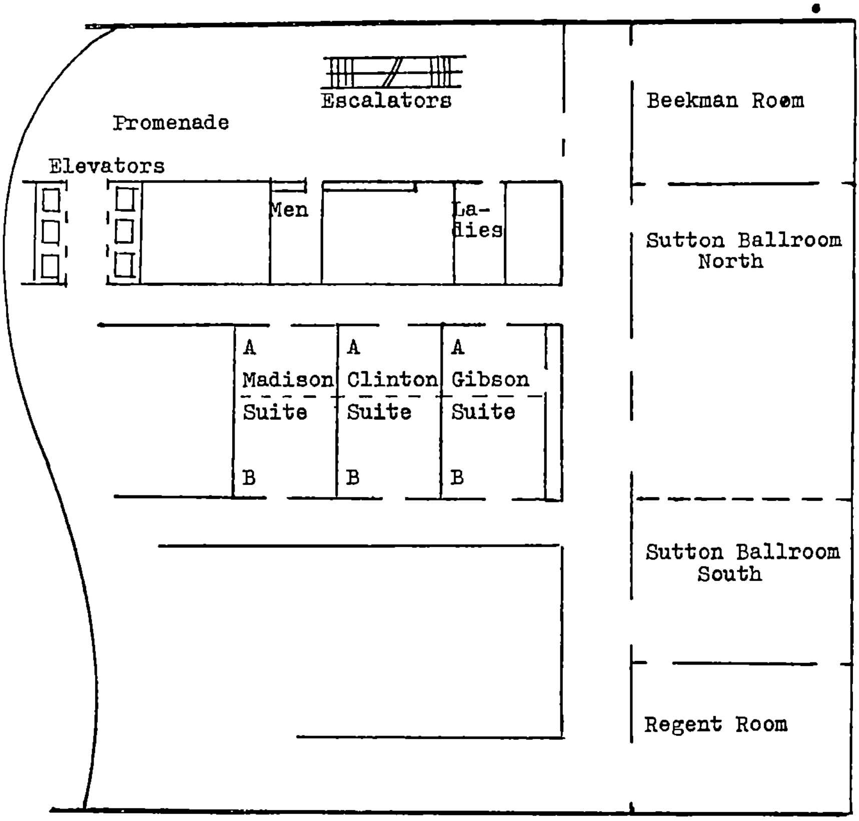
## LENGTH OF PAPERS

Invited papers are designated with an asterisk in this program. Ordinarily, invited papers are scheduled for 30 minutes, with an additional 10 minutes for discussion. Contributed papers are scheduled for 10 minutes with an additional 5 minutes for discussion. The program is rather tightly scheduled and all authors are urged to stay within their time allowance.

## DESIGNATION OF SESSIONS AND PAPERS

Abbreviations are used to identify the technical sessions and papers in these sessions. The first letter denotes day of the week, and is **W**, **T**, or **F**. The second letter denotes AM or PM, and is **A** or **P**. A number from 1 to 5 occurs next, and identifies which of the five simultaneous sessions is being considered, including the room for the session. Here, 1 denotes the Sutton Ballroom North, 2 the Sutton Ballroom South, 3 the Beekman Room, 4 the Regent Room, and 5 the Madison Suite. Finally, following a period, the last number identifies the location (ordinarily of a paper) within the session. When the entire session is a panel discussion, the period and following number do not occur. For example, **WA4.3** designates the third paper in session 4 (the Regent Room) on Wednesday morning.

The two luncheons and banquet are also meeting sessions. The Wednesday luncheon is session **WPL**, the Banquet is **TPB**, and the Friday luncheon is **FPL**.



Second Floor - The New York Hilton

## THE NEW YORK ORSA MEETING—May 31 to June 2, 1967

*Sessions:* 1—Sutton Ballroom North
2—Sutton Ballroom South
3—Beekman Room
4—Regent Room
5—Madison Suite
*Headquarters:* Gibson Suite
*Ladies:* Clinton Suite
*Books:* To be announced
*Luncheons* (5/31 and 6/2): Trianon Ballroom } Third Floor
*Reception* (6/1): Le Petit Trianon } Third Floor
*Dinner* (6/1): Trianon Ballroom } Third Floor
*Registration:* Sutton Corridor or Promenade

# COMMITTEE FOR THE NEW YORK MEETING

| | |
|---|---|
| *Meeting Chairman:* | Gordon D. Shellard<br>*New York Life Insurance Company*<br>*51 Madison Avenue, New York, N. Y.* |
| *Program Chairman:* | Denos C. Gazis<br>*IBM Research Center*<br>*Box 218, Yorktown Heights, N. Y.* |
| *Arrangements Chairman:* | Walter Helly<br>*The Polytechnic Institute of Brooklyn*<br>*333 Jay Street, Brooklyn, N. Y.* |
| *Registration Chairman:* | H. David Grace<br>*The Celanese Corporation*<br>*522 Fifth Avenue, New York, N. Y.* |
| *Associate Arrangements Chairmen:* | Kenneth W. Crowley<br>*The Port of New York Authority*<br>*111 Eighth Avenue, New York, N. Y.*<br>Kenneth M. Curtin<br>*Infret Corporation of America*<br>*80 Wall Street, New York, N. Y.* |
| *Ladies Program Chairmen:* | Alice Feeney<br>*51 Barrow Street, New York, N. Y.*<br>Dorothy Helly<br>*91 Central Park West, New York, N. Y.* |

## SESSION CHAIRMEN

| | |
|---|---|
| **WA1** | Ernest H. Weinwurm |
| **WA2** | James C. DeHaven |
| **WA3** | Rolf A. Deininger |
| **WA4** | W. Edward Cushen |
| **WP1** | William Dorfman |
| **WP2** | Norman T. J. Bailey |
| **WP3** | David B. Hertz and Albert Madansky |
| **WP4** | Leslie C. Edie |
| **WP5** | Ellis L. Johnson |
| **TA1** | E. S. Winlund |
| **TA2** | Kalman J. Cohen |
| **TA3** | Manfred Kochen |
| **TA4** | Shirleigh Silverman |
| **TA5** | George E. Nicholson, Jr. |
| **TP1** | Murray Greyson |
| **TP2** | Ralph E. Gomory |
| **TP3** | George J. Feeney |
| **TP4** | Robert E. Machol |
| **TP5** | Alan J. Rowe and Donald G. Malcolm |
| **FA1** | Gordon M. Gershon |
| **FA2** | Alan J. Hoffman |
| **FA3** | Donald F. Heany |
| **FA4** | Martin K. Starr |
| **FP1** | Robert R. Hare, Jr. |
| **FP2** | George H. Weiss |
| **FP3** | Andrew Vazsonyi |
| **FP4** | Paul E. Jones, Jr. |

# SUMMARY OF EVENTS

| | *Title* | *Time* | *Room* |
|---|---|---|---|
| | **Wednesday, May 31** | **AM** | |
| **WA1** | Cost-Effectiveness Applications in Industry | 9:00–Noon | Sutton Ballroom North |
| **WA2** | Operations Research in Medical Care and Education | 9:00–Noon | Sutton Ballroom South |
| **WA3** | Operations Research and the Quality of our Environment | 9:00–Noon | Beekman Room |
| **WA4** | Non-Military Government Applications | 9:00–Noon | Regent Room |
| | **Wednesday, May 31** | **PM** | |
| **WPL** | Luncheon | 12:15– 1:45 | Trianon Ballroom |
| **WP1** | Cost-Effectiveness | 2:00– 5:00 | Sutton Ballroom North |
| — | Cost-Effectiveness Section: Business Meeting | 5:00–5:30 | Sutton Ballroom North |
| **WP2** | Medical and Hospital Applications | 2:00–5:00 | Sutton Ballroom South |
| **WP3** | Panel On: Using OR Effectively in Advertising and Marketing—Why and How | 2:00–5:00 | Beekman Room |
| **WP4** | Transportation Science Section | 2:00–5:00 | Regent Room |
| — | Transportation Science Section: Business Meeting | 5:00–5:15 | Regent Room |
| **WP5** | Production and Inventory Control | 2:00–5:00 | Madison Suite |
| | **Thursday, June 1** | **AM** | |
| **TA1** | Panel On: Cost-Effectiveness Inpact of DOD Directive 3200.9 | 9:00–Noon | Sutton Ballroom North |
| **TA2** | Operations Research in Banking | 9:00–Noon | Sutton Ballroom South |
| **TA3** | Information Retrieval | 9:00–Noon | Beekman Room |
| **TA4** | Space, Politics and Natural Resources | 9:00–Noon | Regent Room |
| **TA5** | Queueing and Statistics | 9:00–Noon | Madison Suite |

| | *Title* | *Time* | *Room* |
|---|---|---|---|
| | **Thursday, June 1** | **PM** | |
| — | Operations Research Society of America Annual Business Meeting | 12:00–12:15 | SUTTON BALLROOM NORTH |
| **TP1** | Military Applications Section-I | 2:00–5:00 | SUTTON BALLROOM NORTH |
| — | Military Applications Section: Business Meeting | 5:00–5:30 | SUTTON BALLROOM NORTH |
| **TP2** | Networks and Mathematical Programming | 2:00–5:00 | SUTTON BALLROOM SOUTH |
| **TP3** | Finance and Corporate Planning | 2:00–5:00 | BEEKMAN ROOM |
| **TP4** | Transportation | 2:00–5:00 | REGENT ROOM |
| **TP5** | Analytic and Computer Approaches in Production | 2:00–5:00 | MADISON SUITE |
| — | Cocktail Party | 6:00–7:30 | LEPETIT TRIANON |
| — | Banquet | 7:30–9:00 | TRIANON BALLROOM |
| | **Friday, June 2** | **AM** | |
| **FA1** | Military Applications Section—II | 9:00–Noon | SUTTON BALLROOM NORTH |
| **FA2** | New Analytical Techniques | 9:00–Noon | SUTTON BALLROOM SOUTH |
| **FA3** | Recruitment, Training and Careers in OR | 9:00–Noon | BEEKMAN ROOM |
| **FA4** | Production Management and Product Design | 9:00–Noon | REGENT ROOM |
| | **Friday, June 2** | **PM** | |
| **FPL** | Luncheon | 12:15–1:45 | TRIANON BALLROOM |
| **FP1** | Military Applications Section—III | 2:00–5:00 | SUTTON BALLROOM NORTH |
| **FP2** | Allocation Problems, Control Theory and Systems | 2:00–5:00 | SUTTON BALLROOM SOUTH |
| **FP3** | Management Information Systems and Quantitative Techniques | 2:00–5:00 | BEEKMAN ROOM |
| **FP4** | a) Information Retrieval | 2:00–3:30 | REGENT ROOM |
| | b) New Applications | 3:30–5:00 | REGENT ROOM |

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Rubel, R. A.: **WA2.1**
Ryan, J. T.: **TP1.4**

Samuelson, R. L.: **FP3.5**
Schaefer, T. J.: **TA4.6**
Schotta, C. Jr.: **WA2.9, FP4.7**
Schrady, D. A.: **WP5.9**
Selman, J. H. N.: **FP2.5**
Serfozo, R. F.: **TP4.2**
Sherwani, J. K.: **WA3.2**
Silver, A. N.: **TA5.8**
Silverman, S.: **TA4**
Singleton, R. R.: **FA3.3**
Sivazlian, B. D.: **WP5.2**
Smith, K. V.: **TA2.4, FP3.1**
Smith, S. B.: **TP2.1**
Smith, W. T.: **WP1.7**
Smollen, W. J.: **WA1.2**
Sorensen, E. E.: **WP4.4**
Soriano, A.: **WP5.4**
Spielberg, K.: **TP2.7**
Sprague, C. F.: **FP4.3**
Srygley, J. G.: **TA4.2**
Stanly, A. L.: **WA2.7**
Starr, M. K.: **FA4**
Stasch, S. F.: **FP3.4**
Steen, P. J.: **TP1.2**
Stephenson, G.: **WP5.3**
Stockfisch, J. A.: **FP1.1**
Strieb, M. I.: **TA4.6**
Strotz, R.: **WA3.4**
Sullivan, W. J.: **WP4.4**
Swersey, R. J : **WP5.6**

Thomas, M. E.: **FP2.2**
Thornton, R. H.: **TP1.4**
Tiede, R. V.: **FP1.2**
Tinsley, W. F.: **TP1.5**
Tomeski, E.: **WP5.3**

Vazsonyi, A.: **FP3**
Vuchic, V. R.: **WP4.5**

Wagner, H. M.: **TP5.4**
Weinstock, J.: **FP1.5**
Weinwurm, E. H.: **WA1**
Weiss, G. H.: **FP2**
Welker, R. A : **TA4.5**
Wersan, S. J.: **WA3.3**
Whinston, A.: **TP2.6**
Whitehouse, G. E.: **TA5.2**
Whitty, W. J.: **TP4.6**
Wolff, R. W.: **TA5.6**
Wollmer, R. D.: **TP2.2**
Will, R. B.: **FP2.6**
Wilson, J. B.: **FA2.3**
Wilson, M. A.: **TP2.3**
Winlund, E. S.: **TA1**
Wright, C.: **WA3.4**

Yahya, Q. A. M. M.: **FP2.9**
Young, J. P.: **WA2.2**
Young, S.: **WP1.2**
Yuan, J. S. C.: **TP5.4**

# PROGRAM

of the

# THIRTY-FIRST NATIONAL MEETING

of the

# OPERATIONS RESEARCH SOCIETY OF AMERICA

**WEDNESDAY AM, MAY 31** SUTTON BALLROOM NORTH

Session WA1: 9:00 A.M.–Noon

## Cost Effectiveness Applications in Industry

*Chairman:* ERNEST H. WEINWURM

*De Paul University, Chicago, Illinois.*

**WA1.1** ***Cost Effectiveness Analysis of Information Systems,** MALCOLM H. GOTTERER, *Pennsylvania State University, University Park, Pennsylvania.*

**WA1.2** **Panel of Industry Experts:**

JOHN B. LATHROP, *Advanced Methods Department, Lockheed California Corporation, Burbank, California.*

ROBERT A. MOCELLA, *International Minerals and Chemical Corporation, Skokie, Illinois.*

JOHN J. ROSATI, *Information Systems Staff, TRW Systems, Redondo Beach, California.*

WILLIAM J. SMOLLEN, *North American Aviation, Inc., Los Angeles Division, International Airport, Los Angeles, California.*

(Abstract **WA1.2** contains an outline of the subject matter for this panel discussion.)

* An asterisk identifies an invited paper.

WEDNESDAY AM, MAY 31 SUTTON BALLROOM SOUTH

Session WA2: 9:00 AM–Noon

## Operations Research in Medical Care And Education

*Chairman:* JAMES C. DEHAVEN

*The RAND Corporation, 1700 Main Street, Santa Monica, California.*

**WA2.1** **The Application of Statistical Decision Theory to the Treatment of a Sore Throat,** RONALD A. RUBEL, *Doctoral House, Harvard Business School, Boston, Massachusetts.*

**WA2.2** **Sequential Scheduling Models for Hospital Elective Patients,** MICHAEL RESH and JOHN P. YOUNG, *The Johns Hopkins University, Baltimore, Maryland.*

**WA2.3** **A Systems Approach to Design of an Ambulatory Patient Department,** LLOYD C. GRISDALE and JACK GOLDSTEIN, *TRW Systems, 1 Space Park, Redondo Beach, California*

**WA2.4** **Cost, Effectiveness and Patient Care,** DANIEL HOWLAND, *Department of Business Organization, The Ohio State University, Columbus, Ohio*

**WA2.5** **Minimizing the Hospital Ration Cost through Linear Programming,** FROMAN HULBERT, *U. S. Air Force, 2nd Arsenal, St. Louis, Missouri.*

**WA2.6** **Decision Making in the Hospital Environment,** H. D. DUNN, and A. HINDLE, *Department of Operational Research, University of Lancaster, Lancaster, England*

**WA2.7** **Site Optimization of a Health Sciences Center—A Problem in Optimization of Non-Commensurate Data and Criteria,** A. L. STANLY and CALVIN DAVIS, *TRW Systems, 1 Space Park, Redondo Beach, California.*

**WA2.8** **An Application of the Transportation Model to a Student Assignment Problem,** BENJAMIN LEFKOWITZ, *Stanford Research Institute, Stanford, California.*

**WA2.9** **A Priori Decision Functions for Education Evaluation,** RICHARD B. HOFFMAN, *University of California, Berkeley, California,* and CHARLES SCHOTTA, JR., *University of California, Davis, California.*

WEDNESDAY AM, MAY 31 BEEKMAN ROOM

Session WA3: 9:00 AM–Noon

## Operations Reseach And The Quality Of Our Environment

*Chairman:* ROLF A. DEININGER

*School of Public Health, University of Michigan, Ann Arbor, Michigan.*

WA3.1 ***Operations Research in the Design of Water and Wastewater Treatment Plants,** WALTER R. LYNN, *Environmental Systems Engineering* and DANIEL P. LOUCKS, *Water Resources Engineering, Cornell University, Ithaca, New York.*

WA3.2 ***Operations Research and Water Quality Management,** FREDERICK E. MCJUNKIN and JABBAR K. SHERWANI, *School of Public Health, University of North Carolina, Chapel Hill, North Carolina.*

WA3.3 ***Simulation and Analysis of Refuse Collection Systems,** JIMMIE E. QUON and ABRAHAM CHARNES, *The Technological Institute, Northwestern University, Evanston, Illinois,* and STEPHEN J. WERSAN, *Aerospace Corporation, San Bernadino, California.*

WA3.4 ***A Mathematical and Economic Model of Air Pollution from Stationary Sources,** COLIN WRIGHT, and ROBERT STROTZ, *Department of Economics, Northwestern University, Evanston, Illinois.*

WA3.5 ***Systems Analysis of the Waste Management System of the State of California,** FRANK R. BOWERMAN, *Aerojet-General Corporation, 9100 E. Flair Drive, El Monte, California.*

**WEDNESDAY AM, MAY 31** REGENT ROOM

Session WA4: 9:00 AM—Noon

## Non-Military Government Applications

*Chairman:* W. EDWARD CUSHEN

*National Bureau of Standards, Washington, D.C.*

WA4.1 ***An Example of Applied Operations Research at the U. S. Department of Agriculture,** HEBER BOULAND, *Technical Analysis Division, National Bureau of Standards, Washington, D. C.*

WA4.2 ***Projections of the Level and Distribution of State and Local Government Expenditures for Input-Output Models,** ARNOLD H. PACKER, *Research Triangle Institute, Research Triangle Park, North Carolina.*

WA4.3 ***Multistage Optimization in Water Resource Planning,** W. L. MEIER, JR. and C. S. BEIGHTLER, *College of Engineering, The University of Texas, Austin, Texas.*

WA4.4 ***Teaching Quantitative Techniques to Students of Public Affairs,** W. D. BRINCKLOE, *Graduate School of Public and International Affairs, University of Pittsburgh, Pittsburgh, Pennsylvania.*

**WEDNESDAY PM, MAY 31** TRIANON BALLROOM

Session WPL: 12:15–1:45 PM

## LUNCHEON

*Chairman:* GORDON D. SHELLARD

*New York Life Insurance Company, 51 Madison Avenue,*
*New York, New York.*

*Speaker:* DR. TIMOTHY W. COSTELLO, *Deputy Mayor–City Administrator, Office of the Mayor, The City of New York.*

*Subject:* **Information Systems and City Government.**

WEDNESDAY PM, MAY 31 SUTTON BALLROOM NORTH

Session WP1: 2:00–5:00 PM

## Cost-Effectiveness

*Chairman:* WILLIAM DORFMAN

*Environmental Science Services Administration, Rockville, Maryland.*

**WP1.1** **The Critical Region in Relative Cost Effectiveness,** W. EUGENE REYNOLDS, *Resource Management Consultants, Inc., Bethesda, Maryland.*

**WP1.2** **Cost-Benefit Analysis for Social Welfare Programs—with Special Reference to the AFDC Program,** GORDON K. C. CHEN and STANLEY YOUNG, *School of Business Administration, University of Massachusetts, Amherst, Massachusetts.*

**WP1.3** **The Marginal Productivity Concept of Hiring,** PURNELL H. BENSON, *Rutgers University, Department of Psychology, Newark, New Jersey.*

**WP1.4** **Applications of the Cost/Effectiveness Approach in the Navy's Personnel Research Program,** MARILEE N. CONNELLY, *New Developments Research Department, U. S. Naval Personnel Research Activity, San Diego, California.*

**WP1.5** **A Cost Effectiveness Approach to a University Planning Problem,** PAUL W. HAMELMAN, *West Virginia University, Morgantown, West Virginia.*

**WP1.6** **A Cost-Effectiveness Application: The Value of Beryllium in Spacecraft,** EUGENE R. BRUSSELL, *Hughes Aircraft Company, Space Systems Division, Los Angeles, California.*

**WP1.7** **Effects of Subsystem Reliability on System Cost-Effectiveness,** WILLIAM T. SMITH and EDMUND D. MORRISON, *The Boeing Company, Box 3991, Seattle, Washington.*

WEDNESDAY PM, MAY 31 SUTTON BALLROOM NORTH

5:00 PM–5:30 PM

## Cost Effectiveness Section: Business Meeting

*Chairman:* HARRY P. HATRY, *Section Chairman*

**WEDNESDAY PM, MAY 31** SUTTON BALLROOM SOUTH

Session WP2: 2:00–5:00 PM

## Medical And Hospital Applications

Chairman: NORMAN T. J. BAILEY

*Cornell Medical College, 1300 York Avenue, New York, New York*

**WP2.1** ***Models and Operational Definitions for Comprehensive Patient Care,** CHARLES D. FLAGLE, *School of Hygiene and Public Health, The Johns Hopkins University, Baltimore, Maryland.*

**WP2.2** ***A New Type of Compound Poisson Process with Applications to Medicine and Biology,** WILLIAM J. HORVATH, *Mental Health Research Institute, University of Michigan, Ann Arbor, Michigan.*

**WP2.3** ***Hospital Planning and Operations Research,** PETER COWAN, *Joint Unit for Planning Research, University College, London, England.*

**WP2.4** ***Measures of Effectiveness for the Hospital Medication System,** RICHARD K. C. HSIEH, *U. S. Public Health Service, Baltimore, Maryland*

**WEDNESDAY PM, MAY 31** BEEKMAN ROOM

Session WP3: 2:00–5:00 PM

## Panel On: Using OR Effectively in Advertising And Marketing—Why And How

*Chairmen:*

DAVID B. HERTZ, *McKinsey & Company, Inc., New York, New York,* and ALBERT MADANSKY, *Market Planning Corporation, New York, New York.*

*Panel Members:*

SEYMOUR BANKS, *Leo Burnett Company, Chicago, Illinois.*
CYRIL W. PLATTES, *General Mills, Minneapolis, Minnesota.*
DAVID W. MILLER, *Graduate School of Business, Columbia University, New York, New York.*
TIBOR FABIAN, *Mathematica, Inc., Princeton, New Jersey.*

(Abstract **WP3.1** contains an outline of the subject matter for this panel discussion.)

**WEDNESDAY PM, MAY 31** REGENT ROOM

Session WP4: 2:00–5:00 PM

## Transportation Science Section

*Chairman:* LESLIE C. EDIE
*The Port of New York Authority, New York, New York.*

WP4.1 ***The Synchronization of Traffic Signals for Minimum Delay,** JOHN A. HILLIER, *Road Research Laboratory, Ministry of Transport, London, England* and RICHARD W. ROTHERY, *General Motors Research Laboratories, Warren, Michigan.*

WP4.2 ***Operations Analysis for Transportation Systems Design,** E. FARNSWORTH BISBEE, *Massachusetts Institute of Technology, Cambridge, Massachusetts.*

WP4.3 ***Study of Passenger Allocation and Flows for Scheduling,** J. GILLES GAGNON, *Air Canada, Place Ville Marie, Montreal 2, Quebec, Canada.*

WP4.4 ***Freighter Scheduling Model,** C. A. OLSON, E. E. SORENSEN and W. J. SULLIVAN, *Matson Research Corporation, 215 Market Street, San Francisco, California.*

WP4.5 ***Interstation Spacings for Line-Haul Passenger Transportation,** VUKAN R. VUCHIC, *The Towne School of Civil and Mechanical Engineering, University of Pennsylvania, Philadelphia, Pennsylvania.*

**WEDNESDAY PM, MAY 31** REGENT ROOM

5:00 P.M.–5:15 P.M.

## Transportation Science Section: Business Meeting

*Chairman:* WALTER HELLY, *Section Chairman*

WEDNESDAY PM, MAY 31 MADISON SUITE

Session WP5: 2:00–5:00 PM

## Production And Inventory Control

*Chairman:* ELLIS L. JOHNSON

*Department of Industrial Administration, Yale University,*
*New Haven, Connecticut*

**WP5.1** **An Ordering Policy for Repairable Stock Items,** STEPHEN G. ALLEN and D. A. D'ESOPO, *Stanford Research Institute, Menlo Park, California.*

**WP5.2** **The One-Period Production and Inventory Control Problem of a Multi-Commodity System with Probabilistic Demand and Interacting Set-Up Cost,** B. D. SIVAZLIAN, *Department of Industrial and Systems Engineering, The University of Florida, Gainesville, Florida.*

**WP5.3** **The Machine Loading Problem in Production Systems,** DAVID ROTHENBERG, *Industrial Mathematics, Inc.,* JOHN FOX, *W. R. Grace & Co.,* EDWARD A. TOMESKI and GEORGE STEPHENSON, *Systems and Management Innovation Inc., 2 West 45th Street, New York, New York.*

**WP5.4** **The Effect of Reducing Leadtime on Inventory Levels—Simulation Analysis,** DONALD GROSS, *The George Washington University, Washington, D. C.,* and A. SORIANO, *Institute for Defense Analyses, Arlington, Virginia.*

**WP5.5** **Economic Selection of Inspection Criteria for Item Inspection for Defects in a Multistage Production Process,** LYNWOOD A. JOHNSON, *Department of Industrial Engineering, Georgia Institute of Technology, Atlanta, Georgia.*

**WP5.6** **Unified Production Planning and Control,** ROBERT W. BLANNING and RICHARD J. SWERSEY, *Management Science Center, University of Pennsylvania, Philadelphia, Pennsylvania.*

**WP5.7** **Optimization of an Inventory by Regularly Adjusting the Deterministic Component of the Stochastic Input Process,** HANS KASPAR, *Rocketdyne, North American Aviation, Inc., Canoga Park, California.*

**WP5.8** **Optimal Continuous Review Policies for Two Product Inventory Systems with Joint Setup Costs,** EDWARD IGNALL, *Columbia University, New York, New York.*

**WP5.9** **A Reparable Inventory System with Continuous Repair,** D. A. SCHRADY, *Naval Postgraduate School, Monterey, California.*

THURSDAY AM, JUNE 1 SUTTON BALLROOM NORTH

Session TA1: 9:00 AM–Noon

## Panel On: Cost-Effectiveness Impact Of DOD Directive 3200.9

*Chairman:* E. S. WINLUND

*Douglas Aircraft Co., Santa Monica, California*

*Panel Members:*

JAMES W. GRODSKY, *Office of Assistant Director (Engineering Management), Office of the Director of Defense Research and Engineering, The Pentagon, Washington, D. C.*

COLONEL DONALD H. HEATON, *Deputy Chief of Staff Systems, HQ-AFSC, Andrews Air Force Base, Washington, D. C.*

JACK LIVINGSTON, *Directorate of Procurement Management, Office of the Secretary of Defense for Installation and Logistics, The Pentagon, Washington, D. C.*

PAUL C. GREENLEE, *Advanced Studies Division, Lockheed-Georgia Company, Marietta, Georgia.*

(Abstract **TA1.1** contains rationale and five questions to which panel members will respond. Responses, discussion and recommendations generated prior to meeting will be available as a published paper.)

THURSDAY AM, JUNE 1 SUTTON BALLROOM SOUTH

Session TA2: 9:00 AM–Noon

## Operations Research In Banking

*Chairman:* KALMAN J. COHEN

*Graduate School of Industrial Administration*
*Carnegie Institute of Technology, Pittsburgh, Pennsylvania*

**TA2.1** ***Banking Research: Prospects and Problems,** FREDERICK S. HAMMER, *Federal Deposit Insurance Corporation, 550 17th Street, N. W., Washington, D. C.*
*Discussant:* WILLARD T. CARLETON, *School of Business, Northwestern University, Evanston, Illinois*

**TA2.2** ***Cost Structure of Banks,** IRWIN MILLER, *Arthur D. Little, Inc., 35 Acorn Park, Cambridge, Massachusetts,* and IRVING PLOTKIN, *Massachusetts Institute of Technology, Cambridge, Massachusetts.*
*Discussant:* GEORGE J. BENSTON, *College of Business Administration, University of Rochester, Rochester, New York.*

**TA2.3** ***A Model of Consumer Banking Behavior,** ROBERT L. KRAMER, *Bankers Trust Company, 16 Wall Street, New York, New York.*
*Discussant:* WALTER R. MILLER, JR., *Mellon National Bank and Trust Company, Mellon Square, Pittsburgh, Pennsylvania.*

**TA2.4** ***An Adaptive Model for Investment Management,** JERRY A. POGUE, *Carnegie Institute of Technology, Pittsburgh, Pennsylvania.*
*Discussant:* KEITH V. SMITH, *Graduate School of Business Administration, University of California, Los Angeles, California.*

**THURSDAY AM, JUNE 1** BEEKMAN ROOM

Session TA3: 9:00 AM–Noon

## Information Retrieval

*Chairman:* MANFRED KOCHEN

*Mental Health Research Institute*
*University of Michigan, Ann Arbor, Michigan*

**TA3.1** ***Analysis of Selected Operations Problems in an Automated Library System,** NORM MEISE, *United Aircraft Corporate Systems Center, Farmington, Connecticut.*

**TA3.2** ***The Effect of Response Time upon Utilization of an Information Retrieval System—A Simulation,** ROBERT M. HAYES, *Institute of Library Research, University of California, Los Angeles, California.*

**TA3.3** ***An Algebraic Model for the Processing of Formatted Files,** W. D. FRAZER, *International Business Machines Corporation, Thomas J. Watson Research Center, Yorktown Heights, New York.*

**TA3.4** ***A Literature Search Model,** FERDINAND F. LEIMKUHLER, *School of Industrial Engineering, Purdue University, Lafayette, Indiana.*

**TA3.5** ***Measures for the Comparison of Information Retrieval Systems, and the Normalized Sliding Ratio,** STEPHEN POLLOCK, *Naval Postgraduate School, Monterey, California.*

P9544

THURSDAY AM, JUNE 1 REGENT ROOM

Session TA4: 9:00 AM–Noon

## Space, Politics And Natural Resources

*Chairman:* SHIRLEIGH SILVERMAN

*National Bureau of Standards, Washington, D. C.*

TA4.1 **Space Station Mission Simulation Mathematical Model,** TRAVIS E. PEACE, *General Dynamics Corporation, Fort Worth, Texas.*

TA4.2 **A Computer Model for Scheduling Crew Activities for Long-Duration Space Missions,** JAMES G. SRYGLEY, *Fort Worth Division of General Dynamics, Operations Research, Fort Worth, Texas.*

TA4.3 **Experiment Selection for Manned Space Flights,** JOHN K. HANCOCK, *Martin Marietta Corporation, P. O. Box 179, Denver, Colorado.*

TA4.4 **A Research and Development Cost Spreading Technique,** MELVIN E. CAPEHART, *Martin Company, Denver, Colorado.*

TA4.5 **Application of Linear Programming Techniques to Space System Operations Scheduling,** SIDNEY I. FIRSTMAN and RUSSELL A. WELKER, *Aerospace Effectiveness Department, Planning Research Corporation, 1100 Glendon Avenue, Los Angeles, California.*

TA4.6 **A Quasi-Optimal Scheduler for a Ground Radar Tracking Satellites at High Rates,** D. LOBEL, *RCA, Moorestown, New Jersey,* T. J. SCHAEFER and M. I. STRIEB, *Kettelle Associates, Inc., Paoli, Pennsylvania.*

TA4.7 **Operations Research Techniques in Politics,** MIKLOS WASS DE CZEGE, *Wass Associates, 617 Central Trust Tower, Cincinnati, Ohio.*

TA4.8 **Optimum Operations of Multi-Reservoir Water Supply System,** REUVEN AMIR, *The Service Bureau Corporation, 2450 Watson Court, Palo Alto, California.*

TA4.9 **Optimal Control of Wildland Fires,** ALAN W. MCMASTERS, *Department of Operations Analysis, Naval Postgraduate School, Monterey, California.*

**THURSDAY AM, JUNE 1** MADISON SUITE

Session TA5: 9:00 AM–Noon

## Queueing And Statistics

*Chairman:* GEORGE E. NICHOLSON, JR.

*Department of Statistics, University of North Carolina,*
*Chapel Hill, North Carolina.*

**TA5.1** **Finite, Closed-Loop Queueing Systems with Time Lags,** MORTON POSNER and B. BERNHOLTZ, *Department of Industrial Engineering, University of Toronto, Toronto 5, Canada.*

**TA5.2** **Solution of M/G/1 and GI/M/1 Finite Queueing Problems by Graphical Means,** GARY E. WHITEHOUSE, *Department of Industrial Engineering, Lehigh University, Bethlehem, Pennsylvania.*

**TA5.3** **A Numerical Method for Constructing Tables for Transition Probabilities and Related Measures for Some Infinite Queueing Systems,** U. NARAYAN BHAT and STUAPT H. MANN, *Operations Research Group, Case Institute of Technology, Cleveland, Ohio.*

**TA5.4** **Queues with Semi-Markovian Arrivals,** ERHAN ÇINLAR, *Northwestern University, Evanston, Illinois.*

**TA5.5** **An Analytical Study of a Monte Carlo Simulation Program to Solve the General Queue Length Problem for Several Service Stations,** DAVID P. REILLY, *General Electric Company, Re-Entry Systems Department, Philadelphia, Pennsylvania.*

**TA5.6** **Work Conserving Priorities,** RONALD W. WOLFF, *Department of Industrial Engineering and Operations Research, University of California, Berkeley, California.*

**TA5.7** **A Class of Tests of Hypotheses of Components of Variance,** SOL HABERMAN, *Applied Physics Laboratory, The Johns Hopkins University, 8621 Georgia Avenue, Silver Spring, Maryland.*

**TA5.8** **On the Evaluation of a Class of Cumulative Probability Integrals Containing Bessel Function Products Using Generating Functions of Orthogonal Polynomials,** AARON N. SILVER, *The Martin Company, Systems Analysis, P. O. Box 179, Denver, Colorado.*

THURSDAY NOON, JUNE 1 SUTTON BALLROOM NORTH

12:00 NOON–12:15 PM

### Operations Research Society of America

## Annual Business Meeting

*Chairman:* JOHN F. MAGEE, *President,*
*Operations Research Society of America*

THURSDAY PM, JUNE 1 SUTTON BALLROOM NORTH

Session TP1: 2:00–5:00 PM

## Military Applications Section–I

*Chairman:* MURRAY GREYSON

*Strategic Studies Center, Stanford Research Institute, Menlo Park, California.*

TP1.1 ***The Theory and Application of Metagames,** NIGEL HOWARD, *University of Pennsylvania, Philadelphia, Pennsylvania.*

TP1.2 ***An Error Analysis of Range-Only Location and Tracking Systems,** PATRICK J. STEEN and HOWARD EISNER, *Operations Research Incorporated, Silver Spring, Maryland.*

TP1.3 ***Reliability-Maintainability Model of a Complex System,** WILLIAM H. COOK, *Operations Research Incorporated, Silver Spring, Maryland.*

TP1.4 **A Recovery and Reconstitution Model for the Strategic Strike Forces,** JOSEPH T. RYAN and ROBERT H. THORNTON, *Research Triangle Institute, P. O. Box 12194, Research Triangle Park, North Carolina.*

TP1.5 **The Role of Cost Effectiveness in the Preliminary Design of Vertical Lift Military Aircraft,** WILLIAM F. TINSLEY, *Preliminary Design Division, U. S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia.*

TP1.6 **The Use of Order Statistics in Estimation,** H. LEON HARTER, *Aerospace Research Laboratories, Wright-Patterson AFB, Ohio.*

THURSDAY PM, JUNE 1 SUTTON BALLROOM NORTH

5:00–5:30 PM

## Military Applications Section: Business Meeting

*Chairman:* MARTIN N. CHASE, *Section Chairman*

**THURSDAY PM, JUNE 1** SUTTON BALLROOM SOUTH

Session TP2: 2:00–5:00 PM

## Networks and Mathematical Programming

*Chairman:* RALPH E. GOMORY

*IBM Research Center, Box 218, Yorktown Heights, New York*

**TP2.1** **Solution of the 1-Center Problem, the m-center Problem and the Location-Allocation Problem,** MYRON R. ROSENTHAL and SPENCER B. SMITH, *Department of Industrial Engineering, Illinois Institute of Technology, Chicago, Illinois.*

**TP2.2** **Maximizing Flow Through a Network with Node and Arc Capacities,** RICHARD D. WOLLMER, *The RAND Corporation, 1700 Main Street, Santa Monica, California.*

**TP2.3** **Contingency Modeling by Oriented Graphs,** MYRON A. WILSON, *General Electric Company, Re-Entry Systems Dept., Philadelphia, Pennsylvania.*

**TP2.4** **Analysis of Algorithms for the Zero-One Programming Problem,** RONALD L. GUE and KENNETH C. CAIN, *Department of Industrial and Systems Engineering, University of Florida, Gainesville, Florida.*

**TP2.5** **Decomposition Programming, Macro-Micro Structure,** EARL J. BELL, *School of Business Administration, University of Washington, Seattle, Washington.*

**TP2.6** **An Algorithm for the Quadratic Assignment Problem,** G. W. GRAVES, *Western Management Science Institute, University of California, Los Angeles, California,* and ANDREW B. WHINSTON, *Purdue University, Lafayette, Indiana.*

**TP2.7** **A Plant Location Algorithm Related to Direct Search Mixed Integer Programming,** KURT SPIELBERG, *IBM Scientific Center, New York, New York.*

**TP2.8** **A Nonlinear Programming Approach to Facilities Location Problems,** ROBERT F. LOVE, *University of Wisconsin, Madison, Wisconsin.*

**TP2.9** **The Tank Assignment Problem II,** LAWRENCE BRISKIN, *The Carborundum Company, Niagara Falls, New York.*

**TP2.10** **Solution Characteristics of Zero-Sum Games by an Approximation Technique,** JAMES C. HECKMAN, *Hughes Aircraft Company, Space Systems Division, El Segundo, California.*

THURSDAY PM, JUNE 1 BEEKMAN ROOM

Session TP3: 2:00–5:00 PM

## Finance and Corporate Planning

*Chairman:* GEORGE J. FEENEY

*General Electric Company, New York, New York.*

**TP3.1** ***A Dynamic Modeling Approach To Bank Asset Management,** A. J. PHIPPS, JR., *Bonner & Moore Associates, Inc., 500 Jefferson Building, Houston, Texas 77002*

**TP3.2** ***Environmental Modeling and Product Conceptualization,** ROBERT D. DAHLE, *Xerox Corporation, P. O. Box 1540, Rochester, New York.*

**TP3.3** ***Regulation in the Finance Industry: New Frontier for Operations Research,** JOHN D. HOGAN, *The Northwestern Mutual Life Insurance Company, 720 East Wisconsin Avenue, Milwaukee 2, Wisconsin.*

**TP3.4** ***Empirical Tests of the Compatibility of Selected Equity Share Price Equations With A Descriptive Dividend Model,** JAMES L. BICKSLER, *Stanford Research Institute, Menlo Park, California.*

## THURSDAY PM, JUNE 1

Regent Room

Session TP4: 2:00–5:00 PM

# Transportation

*Chairman:* Robert E. Machol

*School of Business, Northwestern University, Evanston, Illinois*

TP4.1 **Optimum Transportation Network by Mechanical Analogy,** Claude Riveline, *Paris School of Mines, 60, Boulevard Saint-Michel, Paris ($6^0$), France.*

TP4.2 **A Method for Determining the Optimal Composition of an Aircraft Fleet,** Richard F. Serfozo, *The Boeing Company, Box, 399 Seattle, Washington.*

TP4.3 **A Global Optimization Problem in Bus Scheduling—Satisfaction of Passenger Demand with Minimum Number of Coaches and Crews Subject to Constraints of Union Contracts on Crew's Working Conditions,** Yoshiro Kuratani, *Case Institute of Technology, Cleveland, Ohio,* Mitsuhiko Murate, *Nagoya Railways, Nagoya, Japan* and Toshio Ochi, *Hideo Nagae, Nitachi, Ltd., Tokyo, Japan.*

TP4.4 **The Delivery Problem,** Robert L. Hayes, *Graduate School of Industrial Administration, Carnegie Institute of Technology, Pittsburgh, Pennsylvania.*

TP4.5 **On the Solution of Truck Dispatching Problems by Combinatorial Programming,** John F. Pierce, *Massachusetts Institute of Technology, Cambridge, Massachusetts.*

TP4.6 **Detection of Acceleration in Car-Following,** William J. Whitt and Lucien Duckstein, *Systems Engineering Department, The University of Arizona, Tucson, Arizona.*

TP4.7 **The Oversaturated Signalized Intersection: Some Interarrival Statistics and a Probability Model,** Clinton J. Ancker, Jr. and Antranig V. Gafarian, *System Development Corporation, 2500 Colorado Avenue, Santa Monica, California.*

TP4.8 **Dynamic Control of Traffic Input into an Urban Complex,** William D. Rabin and Lucien Duckstein, *Systems Engineering Department, The University of Arizona, Tucson, Arizona.*

TP4.9 **An Urban Transit Laboratory,** Ernest B. Cohen, Theodore Gordon, and Solomon Moldoff, *General Electric Company, P. O. Box 855, Philadelphia, Pennsylvania.*

THURSDAY PM, JUNE 1 MADISON SUITE

Session TP5: 2:00–5:00 PM

## Analytic and Computer Approaches In Production

*Chairmen:*

ALAN J. ROWE, *School of Business, University of Southern California, Los Angeles, California,* and

DONALD G. MALCOLM, *Management Technology, Inc., 8939 S. Sepulveda Blvd., Los Angeles, California.*

**TP5.1** ***An Heuristic Approach to Combinatorial Decision Problems,** A. J. ROWE, *University of Southern California, Los Angeles, California.*

**TP5.2** ***Comparative Analysis of Real Time Simulation,** JOHN COLLEY, *Research Triangle Institute, Durham, North Carolina.*

**TP5.3** ***Design of Computerized Workload Forecast and Shop Loading System,** D. G. MALCOLM, *Mangement Technology Inc., Los Angeles, California.*

**TP5.4** ***Algorithms for Optimal Production Scheduling and Employment Smoothing,** STEVEN A. LIPPMAN, ALAN J. ROLFE, HARVEY M. WAGNER and JOHN S. C. YUAN. *Stanford University, Palo Alto, California.*

**TP5.5** ***A Loading Problem in Process Type Production,** SALAH E. ELMAGHRABY, *Yale University, New Haven, Connecticut.*

**TP5.6** ***An Ordering Policy when Delivery Can Be Expedited,** S. G. ALLEN and D. A. D'ESOPO, *Stanford Research Institute, Menlo Park, California.*

THURSDAY PM, JUNE 1 LE PETIT TRIANON

6:00–7:30 PM

## Cocktail Party

**THURSDAY PM, JUNE 1** TRIANON BALLROOM

7:30–9:00 PM

## Banquet

### Retiring Presidential Address

*Chairman:* GEORGE SHORTLEY

*Booz-Allen Applied Research, Inc., Bethesda, Maryland*
*Speaker:* JOHN F. MAGEE

*President, Operations Research Society of America, 1966–1967*
*Arthur D. Little, Inc., Cambridge, Massachusetts*

**FRIDAY AM, JUNE 2** SUTTON BALLROOM NORTH

Session FA1: 9:00 AM–Noon

## Military Applications Section—II

*Chairman:* GORDON M. GERSHON

*Stanford Research Institute, Menlo Park, California.*

FA1.1 ***Methods for Classifying Terrain and Introducing Terrain Effects into Analytical Models of Low Altitude Defense System Effectiveness,** RICHARD H. ROSE and LARRY T. ROTH. *Caywood-Schiller, Associates, Chicago, Illinois.*

FA1.2 ***Fighter Aircraft Evaluation for Aerial Combat,** DON W. MOODY, *The Boeing Company, Box 3991, Seattle, Washington.*

FA1.3 ***System Analysis of a Low Altitude Air Defense Weapon,** LARRY B. JAMES, *Douglas Aircraft Co., 5301 Bolsa Avenue, Huntington Beach, California.*

FA1.4 **A Simple Operational Model for Evaluating Increased Performance in a Tactical System,** GENTRY LEE and W. L. PADIA, *Systems Analysis, The Martin Company, Denver, Colorado.*

FA1.5 **A Dynamic Detection and Sequential Allocation Problem,** JOHN R. HOLDSWORTH, *The Bissett-Berman Corp., 2941 Nebraska Ave., Santa Monica, California.*

FA1.6 **A Model Using Approximate Silhouettes to Compute the Probability of a Single Shot Kill,** LAWRENCE J. GRANT, *Lockheed Missiles and Space Company, Sunnyvale, California.*

FRIDAY AM, JUNE 2 SUTTON BALLROOM SOUTH

Session FA2: 9:00 AM–Noon

## New Analytical Techniques

*Chairman:* ALAN J. HOFFMAN

*IBM Research Center, Box 218, Yorktown Heights, New York.*

**FA2.1** ***Finite-State Processes and Dynamic Programming,** R. M. KARP and M. HELD, *IBM Watson Research Center, Yorktown Heights, New York.*

**FA2.2** ***Geometric Programming,** ELMOR PETERSON, *University of Michigan, Ann Arbor, Michigan*

**FA2.3** ***Methodology for the Precise Handling and Manipulation of Qualitative Information,** R S. LEDLEY and JAMES B. WILSON, *National Biomedical Research Foundation, Silver Spring, Maryland.*

**FA2.4** ***Progress in Integer Programming,** MICHEL BALINSKI, *City University of New York, New York, New York.*

FRIDAY AM, JUNE 2 BEEKMAN ROOM

Session FA3: 9:00 AM–Noon

## Recruitment, Training And Careers In OR

*Chairman:* DONALD F. HEANY

*General Electric Company, 570 Lexington Avenue, New York, New York.*

**FA3.1** ***Industry's Changing Man Specifications for OR Positions,** HERBERT HALBRECHT, *Halbrecht Associates, Inc., Washington, D. C.*

**FA3.2** ***OR Courses for OR Clients,** DONALD S. HOLMES, *Graduate Studies, Union College, Schenectady, New York.*

**FA3.3** ***Quantitative Studies in a Liberal Arts College,** ROBERT R. SINGLETON, *College of Quantitative Studies, Wesleyan University, Middletown, Connecticut.*

**FA3.4** ***Effecting a Blend Between OR and Information System Design Work,** ERICOLE ROSA, *Corporate Information Systems Education Department, International Business Machines Corporation, Armonk, New York.*

**FA3.5** ***Operations Research Under Federal Auspices,** JACK R. BORSTING, *Naval Postgraduate School, Monterey, California.*

**FRIDAY AM, JUNE 2** REGENT ROOM

Session FA4: 9:00 AM–Noon

## Production Management And Product Design

*Chairman:* MARTIN K. STARR

*Graduate School of Business, Columbia University,*
*New York, New York.*

**FA4.1** ***What Do You Mean—Product Design?,** KENNETH A. LONGMAN, *Young & Rubicam, Inc., 285 Madison Avenue, New York, New York.*

**FA4.2** ***Modern Automated Shipyard Production Management and Control,** ERNST G. FRANKEL, *Litton Industries, Inc., FDLS Project, 992C West Jefferson Blvd., Culver City, California.*

**FA4.3** ***Schedule Algebra: A Progress Report,** BERNARD GIFFLER, *New York University and C-E-I-R, Inc., Bronx, New York.*

**FA4.4** ***A Bayesian Approach to Minimizing Production Testing Requirements,** LAWRENCE HARRIS, *New York University, Washington Square, New York, New York.*

**FRIDAY PM, JUNE 2** TRIANON BALLROOM

Session FPL: 12:15–1:45 PM

## Luncheon

*Chairman:* DENOS C. GAZIS

*IBM Watson Research Center*
*P.O. Box 218, Yorktown Heights, New York.*

*Speaker:* HOWARD DRESSNER, *Office of the President, The Ford Foundation, New York, New York.*
*Subject:* **Educational Television: The Nation's Forum?**

**FRIDAY PM, JUNE 2** SUTTON BALLROOM NORTH

Session FP1: 2:00–5:00 PM

## Military Applications Section—III

*Chairman:* ROBERT R. HARE, JR.

*Operations Research, Inc., Silver Spring, Maryland.*

**FP1.1** ***Field Experimentation and Small Arms Evaluation,** J. A. STOCKFISCH, *Force Planning and Analysis Office, Department of the Army, Washington, D. C.*

**FP1.2** ***A Reformulation of Ground Combat Missions in Mathematical Programming Form,** ROLAND V. TIEDE, *Research Analysis Corporation, McLean, Virginia.*

**FP1.3** **The Ground Combat Communications Simulator,** DONALD F. BLUMBERG and JAMES F. LOGAN, *Philco-Ford Corporation, TechRep Division, Fort Washington, Pennsylvania.*

**FP1.4** **A Route Selection Model for a Combat Simulation,** GORDON M. CLARK, *Systems Research Group, The Ohio State University, Columbus, Ohio.*

**FP1.5** **Simulation of Over-the-Beach Logistics Operations,** J. WEINSTOCK, *Litton Industries,* and *A. Dobieski, TRW Systems, Space Park, Redondo Beach California.*

**FP1.6** **Comparative Analysis of the Utilization of Commercial and Military Transport and Combat Aircraft,** WILLIAM GRODOWITZ, *Directorate of Aerospace Programs Headquarters, USAF, Washington, D C.*

**FRIDAY PM, JUNE 2** Sutton Ballroom South

Session FP2: 2:00–5:00 PM

## Allocation Problems, Control Theory, and Systems

*Chairman:* George H. Weiss

*National Institutes of Health, Bethesda, Maryland.*

**FP2.1** **Stochastic Allocation Processes,** William D. O'Neil, Jr., *The Bissett-Berman Corporation, 2941 Nebraska Avenue, Santa Monica, California.*

**FP2.2** **An Alternate Derivation of the Discrete Maximum Principle,** Michael E. Thomas, *University of Florida, Gainesville, Florida.*

**FP2.3** **Multichain Markov Renewal Programs,** Bennett L. Fox and Eric V. Denardo, *The RAND Corp., 1700 Main St., Santa Monica, California.*

**FP2.4** **Sequential Pattern Recognition Technique,** George E. Lasker, *Computing Science Department, University of Manitoba, Winnipeg, Manitoba, Canada.*

**FP2.5** **Game Theory Heuristics for Systems Analysis and Design.** Jerome H. N. Selman, *Hq., U. S. Army Munitions Command, Dover, and Stevens Institute of Technology, Hoboken, New Jersey.*

**FP2.6** **System Decisions from Component Testing,** Richard B. Will, *Aerospace Corporation, San Bernardino, California.*

**FP2.7** **Synergistic Processes,** Joseph Bodo, *Sylvania Electronic Defense Labs., Mountain View, California.*

**FP2.8** **Scheduling Several Products on One Machine to Minimize Change-Overs,** C. R. Glassey, *Operations Research Center, University of California, Berkeley, California.*

**FP2.9** **Finite Difference Operator in Operational Research,** Q. A. M. M. Yahya, *Defense Science Organization, Chaklala, West Pakistan.*

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**FRIDAY PM, JUNE 2** BEEKMAN ROOM

Session FP3: 2:00–5:00 PM

## Management Information Systems And Quantitative Techniques

*Chairman:* ANDREW VAZSONYI

*North American Aviation, El Segundo, California.*

**FP3.1** **Alternative Search Procedures for Revising Investment Portfolios,** KEITH V. SMITH, *Graduate School of Business Administration, University of California, Los Angeles, California.*

**FP3.2** **OR in Sales Programs: A Case Study,** T. DONALD DIXON, *Research Analysis Corporation, McLean, Virginia.*

**FP3.3** **Estimation of a Firm's True Total Investment,** PAUL T. GROSS, JR., *Texas A. and M. University, College Station, Texas.*

**FP3.4** **Integrating Operations Research and the Marketing Information System to Improve the Allocation of Marketing Effort,** STANLEY F. STASCH, *School of Business, Northwestern University, Evanston, Illinois.*

**FP3.5** **A Simulation of an Automobile Merit Rating Insurance Operation,** THOMAS H. ROCKWELL and ROY L. SAMUELSON, *Systems Research Group, The Ohio State University, 190 West 19th Avenue, Columbus, Ohio.*

**FP3.6** **Daily Consumer Shopping Behavior under Probabilistic Gravitation,** RICHARD F. BARTON, *School of Business, University of Kansas, Lawrence, Kansas.*

**FP3.7** **A Media Selection Model for On-Line Use with a Time-Shared Computer,** LEONARD M. LODISH and JOHN D. C. LITTLE, *Sloan School of Management, M.I.T., Cambridge, Massachusetts.*

**FP3.8** **SCAN (schedule analysis) and RAPP (resource and project planning), A System Designed for Production Scheduling and Progress Control in a Multi Project and Multi Resource Situation,** W. J. LEYDS, *Philips Tele-communication Industries, Huizen, Netherlands.*

**FRIDAY PM, JUNE 2** REGENT ROOM

Session FP4: 2:00–5:00 PM

## Information Retrieval (2:00-3:30 P.M.) and New Applications (3:30-5:00 P.M.)

*Chairman:* PAUL E. JONES, JR.

*Arthur D. Little, Inc., 35 Acorn Park, Cambridge, Massachusetts.*

### *Information Retrieval*

FP4.1 **A Reference-Connecting Technique for Automatic Information Classification and Retrieval,** MARJORIE J. GREENE, *Operations Evaluations Group, Center for Naval Analyses, 1401 Wilson Blvd., Arlington, Virginia.*

FP4.2 **Normal Text Information Retrieval—Management and Line Use Within IBM,** JOSEPH J. MAGNINO, *IBM Research Center, Box 218, Yorktown Heights, New York.*

FP4.3 **A Mathematical Programming Approach to Automatic Interceptor Selection in Command/Control Systems,** C. FREMONT SPRAGUE III, *Operations Research, 3045 Rosecrans St., Suite 300, San Diego, California.*

FP4.4 **Information Theory Applied to Maintenance Data,** HARALD R. LEUBA, *ARINC Research Corporation, 2551 Riva Road, Annapolis, Maryland.*

### *New Applications*

FP4.5 **Personality Theory and Operations Research,** LAURENCE KASHDAN, *North American Aviation, Inc., 11711 Florence Ave., Santa Fe Springs, California.*

FP4.6 **Some Properties of a Normative Planning Model,** MARK ALFANDARY-ALEXANDER, *U. S. A.E.C., Washington, D. C.*

FP4.7 **Assumptions in Economics: An Operations Research Approach,** RICHARD B. HOFFMAN, *Center for Planning and Development Research, University of California, Berkeley,* and CHARLES SCHOTTA, JR., *Department of Economics, University of California, Davis, California.*

FP4.8 **Administration of Criminal Justice,** RICHARD B. HOFFMAN, *Center for Planning and Development Research, University of California, Berkeley, California.*

# *Abstracts*

**WA1.1 *Cost Effectiveness Analysis of Information Systems,** MALCOLM H. GOTTERER, *Pennsylvania State University, University Park, Pennsylvania.*

Information Systems, especially those that are computer based, are becoming widely used in all facets of the economy. Such systems are, however, expensive to design, implement and maintain. The paper presents an approach to the use of cost-effectiveness techniques in information systems. A distinction is made between efficient allocation of funds for information and the value of information. The veiwpoint is taken that information systems are a capital investment and must have a demonstrated return before they are justified.

**WA1.2 Panel of Industry Experts—Cost Effectiveness Applications in Industry,** Session Chaired by ERNEST H. WEINWURM, *De Paul University, Chicago, Illinois.*

The panelists will report on their experience in using cost effectiveness techniques for business-type applications; problems of installation and communication with other parts of the organization and management will be discussed. Ample time for questions will be reserved.

**WA2.1 The Application of Statistical Decision Theory to the Treatment of a Sore Throat,** RONALD A. RUBEL, *Doctoral House, Harvard Business School, Boston, Massachusetts.*

A patient with a sore throat comes to see a doctor. This illness may be caused either by strep bacteria or by a virus. If the former is the case, penicillin is the indicated treatment; if the latter, only sympotmatic relief (i.e., aspirin) should be prescribed. The doctor has the option of taking a throat culture which will show the absence or presence of strep bacteria. If the sore throat has a strep cause and penicillin is not given, serious complications such as rheumatic fever and glomerulonephritis may result. If the sore throat has a viral cause and penicillin is given, the potential side-effects of the drug should be considered. In this paper, the problem facing the physician, namely whether or not to take a culture and whether or not to prescribe penicillin is solved by means of a Bayesian decision theory model. The doctor supplies the necessary probabilities, while the patient and doctor together are called upon to evaluate the various consequences. The role of the doctor as guardian of society's interest is also discussed. The optimal treatment is calculated by backwards induction.

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* Invited paper

**WA2.2 Sequential Scheduling Models for Hospital Elective Patients,** Michael Resh and John P. Young, *The Johns Hopkins University, Baltimore, Maryland.*

The problem of scheduling elective patients for admission and surgery is dealt with as a two-stage sequence of linear and nonlinear mathematical programming problems, with stochastic constraints and integer solutions. The first stage is concerned with the kind and number of patients to admit, for given bed and operating room capacities; the second stage is concerned with optimal scheduling of operating room use, given the admission data from stage one. Two kinds of elective patients are considered: those whose admission and surgery can be deferred to fit scheduling procedures; and those who must be admitted immediately, but whose surgery can be deferred. Surgical times and postoperative length of stay times are assumed random variables with distributions depending on diagnosis. Mathematical models are formulated, and algorithms are suggested that provide for effective utilization of operating rooms and hospital beds. The models can be generalized to a broad class of sequential scheduling problems that involve a two-stage flow that is subject to capacity and time constraints.

**WA2.3 A Systems Approach to Design of an Ambulatory Patient Department,** Lloyd C. Grisdale and Jack Goldstein, *TRW Systems, 1 Space Park, Redondo Beach, California.*

Evolving Pattern of Medical Care for the Ambulatory Patient—An Application of Operations Research in the Planning of the Ambulatory Patient Department at the University of Alberta Health Sciences Centre, Dr. Lloyd C. Grisdale, Professor of Community Medicine, Faculty of Medicine, University of Alberta, Edmonton, Alberta, Canada and Jack Goldstein, TRW Systems, Redondo Beach, California. TRW Systems Incorporated is presently engaged in a systems study of the Health Sciences Centre at the University of Alberta. As part of this study, planning is being carried out to design the ambulatory patient department to: (1) offer medical students a learning experience that is patient centered rather than disease centered. (2) Cater to the whole socio-economic spectrum of patients rather than only the medically indigent. (3) Introduce concepts of reducing the cost of hospital care by reducing the indiscriminate utilization of the hospital. (4) Provide clinics, staff and equipment to provide unique services to the community. This paper will discuss a systems approach to design of the ambulatory patient department to be compatible with the above objectives and with the functioning of the Health Sciences Centre.

**WA2.4 Cost, Effectiveness and Patient Care,** Daniel Howland, *Department of Business Organization, The Ohio State University, Columbus, Ohio.*

Applications of cost-effectiveness procedures and PPB Systems to health organizations raise a number of problems which stem from the complexity of health organizations and from the difficulty of measuring the psychological and sociological variables which influence their design and operation. Two of the most serious problems are the development of patient-centered system measures of effectiveness for health system models, and methods of assigning costs. These problems suggest the following model criteria: (a) The wide range of social, psychological and physiological variables which provide information for health system decision making must be included. The fact that a variable is hard to measure does not make it unimportant. (b) The models must relate resource utilization policies to their consequences for patients in a way that provides guidance for system design and operation. (c) The models must be general in the sense that they describe a wide range of health systems, and specific in that they can be used to describe specific health organizations. The research leading to the development of a model with these characteristics will be described. This model has evolved through three stages: (1) multiple regression, (2) a predictive cybernetic model, and (3) an adaptable cybernetic model. These models will be described, and the empirical problems of data collection and reduction to construct and test them will be discussed.

**WA2.5 Minimizing the Hospital Ration Cost through Linear Programming,** FROMAN HULBERT, *U.S. Air Force, 2nd Arsenal, St. Louis, Missouri.*

The diet problem at the VA hospital studied by our team is basically the classic cost minimization subject to nutritional constraints. Nine basic constraint equations specify the minimal daily requirements for the following nutrients: calories, protein, iron, calcium, vitamin A, vitamin C, thiamin, riboflavin, and niacin. The food group variables are (1) eggs, (2) meat, fish and poultry, (3) milk, (4) citrus fruit, (5) non-citrus fruit, (6) green and yellow vegetables, (7) other vegetables, (8) potatoes, (9) breads, (10) cereals, (11) desserts, and (12) accessory items. The treatment of the overall problem features three aspects which are to some extent unique: (a) The primary problem of minimizing the total ration is first decomposed into three sub-problems. These are the minimization of the meat, citrus fruit, and green vegetable food groups cost components individually with subsequent incorporation of the sub-optimal solution of these groups into the overall food group-nutrient matrix of the primary problem. (b) The primary and sub-problems incorporate minimum and maximum bounds which are based on patient preference and, in general, diet acceptability. These considerations avoid the impractical aspects of solutions to original diet problems where costs are minimized but palatability, variety or aspects of acceptability are over-ridden. (c) Parametrization of requirements or cost vectors is achieved which adds to the practical value of the application because local costs are subject to random fluctuations.

**WA2.6 Decision Making in the Hospital Environment,** H. D. DUNN, *Project Office,* and A. HINDLE, *Lecturer, Department of Operational Research, University of Lancaster, Lancaster, England.*

This paper describes part of research supported by the British Ministry of Health and being carried out by the Department of Operational Research of the University of Lancaster to develop information systems for Hospital Operation. This work is in two parts. The first is concerned with a study of the short and medium range management decisions made by medically qualified staff and their effect on the use of hospital resources. It is particularly concerned with the effect of alternative admission policies upon such factors as length of waiting list, bed occupancy and probability of refusals and allows management to examine the consequences of alternative operating policies. The simulation model used is illustrated and some preliminary results are given. The second is with a study of the planning of an Out-patient Department and of the information system required for this process. An examination is made of the effect of treating varying proportions of all hospital patients in the Out-patient Department. A model is shown in which the effect of such variations on the basic resources of Doctors, Nurses, Equipment and Buildings are indicated in a quantitative fashion.

**WA2.7 Site Optimization of a Health Sciences Center—A Problem in Optimization of Non-Commensurate Data and Criteria,** A. L. STANLY and CALVIN DAVIS, *TRW Systems, 1 Space Park, Redondo Beach, California.*

The methodology is described for locating some 12 buildings and their key functions comprising a complete Medical and Paramedical Health Science Center for the University of Alberta, Canada. The problem is constrained by the need to integrate the existing teaching hospital with a new medical specialty hospital and by the limited area available. The criteria of goodness comprise a family of cost-effectiveness parameters which include the following: (1) Optimizing travel time for patients, doctors, hospital staff, students, and visitors, (2) Optimizing the cost of the complex while mainatining a high quality center for patient care, teaching, and research, (3) Optimizing the cost of material transfer while providing timely and safe transfer of food, linen, medical specimens, pharmaceuticals, and hard copy. Included in the analysis is the approach for reconciling non-qualitative data and criteria.

**WA2.8 An Application of the Transportation Model to a Student Assignment Problem,** BENJAMIN LEFKOWITZ, *Stanford Research Institute, Stanford, California.*

Stanford Research Institute has been working with the San Francisco Unified School District on a project which seeks to estimate the consequences of implementing alternative student assignment policies. The primary tool in the analysis is the Hitchcock-Koopmans Transportation Model. This paper will describe the practical problems encountered in the application, including racial balance.

**WA2.9 A Priori Decision Functions for Educational Evaluation,** RICHARD B. HOFFMAN, *University of California, Berkeley, California* and CHARLES SCHOTTA, JR., *University of California, Davis, California.*

This paper discusses the application of statistical decision theory to evaluation of educational performance. The initial work has used an a priori decision function. This function was constructed by examining a considerable number of grading policies in a variety of university and college level academic courses and specifying from this an explicit set of grading criteria. Some of the specific attributes of the function include consideration of student improvement factors (using the relationship between performance on each instrument and the course mean).

We are actually performing a parametric study of the weighting factors to show the possible variation in final grades. We also are studying the predictive accuracy of using 1, 2, $\cdots$, n−1 instruments (where $n$ instruments are administered), as well as the predictive accuracy of using any single test instrument. This decision process has the desirable attributes of consistency, reliability and speed. In addition, the objective function used for grading is positive (both when decisions are considered to be made at a fixed point in time and sequentially over time).

### WA3.1 *Operations Research in the Design of Water and Wastewater Treatment Plants, WALTER R. LYNN, *Environmental Systems Engineering* and DANIEL P. LOUCKS, *Water Resources Engineering, Cornell University, Ithaca, New York.*

The design of water and wastewater treatment plants is closely related to the design of biological-chemical processes found in the chemical industry. Various optimization techniques (dynamic, linear and non-linear mathematical programming, simulation, steepest-descent) have been used to assist designers in evaluating operational criteria as well as in the selection of various process units to achieve specified output requirements. For wastewater treatment units some special problems arise involving consideration of the external economic effects of wastewater discharges. Methods for evaluating established standards for wastewater discharges have been lacking. Mathematical deterministic and stochastic models will be presented that can be used by decision-makers as an aid to the development of rational public policies for the control of pollution.

### WA3.2 *Operations Research and Water Quality Management, FREDERICK E. MCJUNKIN and JABBAR K. SHERWANI, *School of Public Health, University of North Carolina, Chapel Hill, North Carolina.*

This paper is concerned with the development of methodologies for determining the set of waste water treatment requirements, not necessarily uniform, that minimizes the total cost of treatment for all interdependent treatment plants within a given river basin. Several mathematical models are formulated with the objectives of maintaining the desired river water quality at minimum cost. The assumptions, logic, and validity of the methodologies are evaluated. Implementation of the model, policies, implications, and consequences are discussed. Specially developed computer programs are reviewed. Procedures for the incorporation of the models in larger, multipurpose systems of water resources are outlined, and parallel applications of the conceptual model to other programs for maintaining environmental quality are suggested.

### WA3.3 *Simulation and Analysis of Refuse Collection Systems, JIMMIE E. QUON and ABRAHAM CHARNES, *The Technological Institute, Northwestern University, Evanston, Illinois,* and STEPHEN J. WERSAN, *Aerospace Corporation, San Bernadino, California.*

The daily route method of refuse collection was simulated mathematically. This method of analysis allows consideration of stochastic variables such as the daily fluctuations in the quantity of refuse produced and the waiting time at the disposal site. It is also a convenient way of experimenting with the operations of a refuse collection system. A functional description of the computer program is given. The initial computations with the simulation program serve to relate performance parameters of the system (overall collection efficiency, haul efficiency, length of workday, etc.) to the characteristics of the system (pickup efficiency, average daily quantity of refuse, daily variability in the quantity of refuse, truck capacity, etc.). The numerical results of computations using a reference set of values for the several input parameters descriptive of the collection system are summarized. Interpretations of the results on a physical basis are given.

**WA3.4 *A Mathematical and Economic Model of Air Pollution from Stationary Sources,** COLIN WRIGHT and ROBERT STROTZ, *Department of Economics, Northwestern University, Evanston, Illinois.*

In this paper a mathematical model is presented which is designed to derive the arrangements of economic variables which are necessary in order for a community experiencing air pollution to achieve a maximum of social welfare from its limited resources. The model assumes the existence of a community which is divided into zones in which individuals and firms locate. Individuals are assumed to obtain utility (welfare) from the goods produced by the firms located within the community, the amount of space they occupy, the location of this space, and receive disutility from the services they sell to the firms and the pollution they encounter from the firms. Firms employ the services offered by individuals in producing goods and combatting air pollution; they also occupy space, and therefore compete with individuals for the same, and are assumed to be affected by the pollutants emitted by other firms. From these assumptions the model designates the optimal price tax solution for solving the Pareto Optimum problem.

**WA3.5 *Systems Analysis of the Waste Management System of the State of California,** FRANK R. BOWERMAN, *Aerojet-General Corporation, 9100 E. Flair Drive, El Monte, California.*

In August, 1965, Aerojet-General Corporation completed contract No. 347 of the State of California Department of Public Health and submitted a final report titled the "California Waste Management Study". That report was the first documented systems approach to the complex problems of wastes and their interrelated pollutional effects—at least the first systems analysis of a state-wide waste management system. Significant findings were an awesome burden of potential pollution from a continually expanding populace, countered by hopeful improvement in the environment by a prompt application of technology as yet unused. "Holding the line" at pollutional loadings of today will prove disasterous in the world of tomorrow, since more people, more autos, more industry, and more of everything except the natural environment will result in unbearable concentrations of pollutants. Systems analysis permits an orderly, step-by-step assessment of the problems—and solutions—on a time-phased schedule. A combining of the expertise of systems engineers with the technical knowledge of the environmental engineers will produce optimal results in a cost-effectiveness frame of reference.

**WA4.1 *An Example of Applied Operations Research at the U.S. Department of Agriculture,** HEBER BOULAND, *Technical Analysis Division, National Bureau of Standards, Washington, D.C.*

Traditionally, the U.S. Department of Agriculture has stayed out of *marketing* or off-farm research but has emphasized *production* or on-farm research; however, with the passage of the Research and Marketing Act of 1946, the Department started putting more effort into Marketing research. Some of this effort went into research on agricultural marketing facilities such as commercial country grain elevators. This is a marketing facility located in a grain producing area to receive, safely store, and ship grain to terminal elevators, mills, and other processing plants. The individual country elevator ranges in size from about 15,000 bushels in the southeast to more than 2 million bushels in the hard winter wheat area of the Central Great Plains. There are about 10,000 country grain elevators in the U.S. with a total storage capacity of close to 2 billion bushels. Investment in these facilities is estimated to be at least $2 billion. Due to changes in grain production and marketing practices many elevator operators are faced with the problem of building new storages or modifying existing facilities. Until recently they have not had adequate guidelines to help them plan their facilities. Most of the design has been done by structural engineering-construction firms who emphasize construction rather than operations. At the U.S. Department of Agriculture, Marketing research on commercial grain storage was done piece meal at first. The purpose of this study is to combine into practical guides for those planning grain elevators some of this fragmented research, some original research, analysis and judgment, and the judgment of experienced elevator operators. The methods for developing guidelines were as follows: (1) Analysis of some basic concepts in storage design. Much of this involved the analysis of areas and volumes of simple geometrical forms. (2) Simulation of handling operations using an electronic computer and a desk calculator. (3) Collection and organization of data—including indirect costs, e.g., truck-waiting cost, and space-shortage cost. An Agricultural Information Bulletin, *Locating, Designing, and Building Country Grain Elevators,* was prepared using these methods. The Bulletin was effectively a do-it-yourself guide using Operations Research. Simplified methods of simulation are illustrated which require no more than an ordinary desk calculator. The Bulletin also makes ample use of visual material such as charts, photographs, engineering drawings, etc. To carry implementation a step farther, the research at the United States Department of Agriculture is diffused through the Federal Extension Service—a part of The Cooperative Extension Service. This is a partnership of three levels of government—Federal, State, and Local—that share in financing, planning, and carrying out educational programs.

**WA4.2 *Projections of the Level and Distribution of State and Local Government Expenditures for Input-Output Models,** ARNOLD H. PACKER, *Research Triangle Institute, Research Triangle Park, North Carolina.*

The mathematical statement of the input-output relationship is: $(I-A)x=b$; where $x$ and $b$ are $n$-dimensional column vectors and $A$ is a matrix of technological input-output coefficients and $I$ is the identity matrix. The elements of $A$, $a_{ij}$, denote the dollars of output of industry $i$ required to produce a dollar of output of industry $j$. Stipulating a net demand vector, $b$, Equation (1) can be solved for the $x$ vector: $x=(I-A)^{-1}\,b$; and the solution compared to sector capacities to estimate utilization on an industry by industry basis. The net demand vector, $b$, can be subdivided into a series of demand vectors $b_1, b_2, \cdots, b_m$, where each column vector, $b_j$, is a component of demand, i.e.: $b=b_1+b_2+\cdots+b_m$. Each of these components can be further sub-divided. This paper is concerned with one subset of these final demand vectors: those corresponding to state and local government purchases of goods and services. The objective was to develop a model to project the vector of net industrial demands resulting from the purchases of goods and services by state and local governments. A regression model was developed for each of five (all inclusive) functions (e.g., education, highways, etc.) from 1957 cross-sectional data. The equations relate purchase expenditures to income, intergovernmental transfers, and population. The expenditure patterns of each function in 1958 were computed from unpublished Office of Business Economics data. The results were then compared to the pattern which would have been experienced if the 1947 distribution of expenditures had persisted.

**WA4.3 *Multistage Optimization in Water Resource Planning,** W. L. Meier, Jr. and C. S. Beightler, *College of Engineering, The University of Texas, Austin, Texas.*

A recent appraisal of Federal water resources research has indicated that research into methods of water resource planning shows most promise of being of immediate and long-term use to governmental agencies. The goal of water resource planning today is to provide for the optimal, multiple use of the resource within a system of development projects. However, the complexity of such systems makes optimal planning a difficult task. Water resource developments form non-serial multistage systems in which storage reservoirs constitute the stages. In this paper an optimization strategy for water resource planning is presented using a combination of dynamic programming and direct search methods. These two techniques are superimposed so as to take advantage of the strong points of each. Problems are formulated as multistage systems with decision variables at each stage corresponding to multiple water uses. The actual non-serial system is decomposed into equivalent serial systems. These serial systems are then optimized using a modified dynamic programming algorithm in which simultaneous decision optimization is accomplished at each stage using an optimum-seeking method. This technique has been programmed for a computer and allows one to determine the optimal size and location of proposed multiple-purpose reservoirs from among alternatives.

**WA4.4 *Teaching Quantitative Techniques to Students of Public Affairs,** W. D. Brinckloe, *Graduate School of Public and International Affairs, University of Pittsburgh, Pittsburgh, Pennsylvania.*

Students who embark on graduate work with public service as a goal—government administration, urban affairs, economic development, international relations, etc.—come from a variety of undergraduate fields, with mathematics or other quantitative majors greatly in the minority. Yet today there are forces involving practitioners in the public sector ever more deeply with various aspects of operations research. The graduate school must correct this "misspent youth" and prepare students within a reasonable time-period to cope with these techniques. The Graduate School of Public and International Affairs at the University of Pittsburgh has experimented for several years with quantitative approaches in degree programs and in mid-career training that are designed to meet this need effectively. The problems and achievements of such programs will be discussed, together with suggestions as to fruitful courses that future graduate programs might take.

**WPl. 1 The Critical Region in Relative Cost Effectiveness,** W. EUGENE REYNOLDS, *Resource Management Consultants, Inc., Bethesda, Maryland.*

System equivalence, from a cost effectiveness standpoint, is defined. Using this definition, the universe is divided into two sets—one in which System A wins and one in which System B wins. The boundary between the sets is a critical region in terms of which system is preferred. The boundary is described parametrically as a function of the characteristics of the competing system. Using this approach, some of the parameters algebraically combine, greatly simplifying the problem of performing sensitivity analyses. Competitions between artillery shells and between ground support aircraft are considered as examples of the technique.

**WPl. 2 Cost-Benefit Analysis for Social Welfare Programs—with Special Reference to the AFDC (Aid to Families with Dependent Children) Program,** GORDON K. C. CHEN and STANLEY YOUNG, *School of Business Administration, University of Massachusetts, Amherst, Massachusetts.*

Cost-benefit analysis has been applied to military operations and public works projects for quite some time. Most of the applications, however, have been limited to those areas where the objects are rather tangible and their costs and benefits lend themselves to some sorts of economic measures. Its uses in non-military government applications, especially where human values are involved such as the social welfare programs, are relatively new and unexplored. This paper is an effort to develop concepts, criteria, and methodogies for measuring the costs and benefits of the AFDC (Aid to Families with Dependent Children) Program as a step toward extending the cost-benefit analysis to social welfare programs.

**WPl. 3 The Marginal Productivity Concept of Hiring,** PURNELL H. BENSON, *Rutgers University, Department of Psychology, Newark, New Jersey.*

The cost principle that factors of production are purchased up to the point where the marginal return from each factor is just equal to its marginal cost is applied to the categorical problem of hiring individual personnel. The description of individual abilities is given in the form of psychological test scores with errors of estimation. The description of individual qualifications involves probability distributions of estimated levels of ability. The integration of these distributions with the ordinate cross-multiplied by the expected marginal return defines a hiring function to be maximized for each applicant. The applicant with the highest optimum is the one to be employed for maximum profitability. The procedure is illustrated by charts which facilitate the combining of information about job specifications with description of individual abilities. The analysis, which has wider application to categorical decisions by management about cost-outlay problems, is a convergence of marginal productivity theory of economics, psychological trait measurement by test scores, and Bayesian principles. The analysis is numerically illustrated by a case of hiring a research chemist.

### WP1.4 Applications of the Cost/Effectiveness Approach in the Navy's Personnel Research Program, Marilee N. Connelly, *New Developments Research Department, U.S. Naval Personnel Research Activity, San Diego, California.*

This paper describes the current development and use of cost/effectiveness methods in the Navy's personnel research program. The author's research in the application of the cost/effectiveness approach to the problems of man/machine function allocation during early stages of system development is emphasized. The cost/effectiveness approach is also discussed in relation to problems of manning assignment and training recommendations.

### WP1.5 A Cost Effectiveness Approach to a University Planning Problem, Paul W. Hamelman, *West Virginia University, Morgantown, West Virginia.*

This paper presents a sketch of a preliminary attempt to apply cost-effectiveness methods to academic planning. A state-supported institution (Camelot University) has adopted a core curriculum policy which requires lower division (Freshman and Sophomore) students to take at least thirty-six semester credit hours from a list of seventy-five basic courses offered by twenty different academic departments. These core courses represent a joint cost of education for all academic departments since all baccalaureate degree candidates, regardless of major field, must satisfy the core curriculum requirements. Forecasts of the number of students enrolling for each core course are based upon the past popularity of each course title and the projected enrollment growth of the university. The problem is to plan the offering of these courses within financial constraints facing the university and consistent with acceptable educational quality levels. An estimate of the cost per full time equivalent faculty member (FTEF) is made for each department. Salaries within each department vary according to market conditions, the mix between junior and senior staff members and the varying teaching loads of the different academic ranks. In all departments, however, the unit (per pupil) cost of instruction diminishes as the section size increases. Preliminary investigation indicates that as section size increases so does the percentage of students failing the course (defined as the number of students receiving a final grade of D or F). A curve plotting the expected failure rate against section size is developed for each core department by a review of student performance in each core discipline over the last several years. This approach is useful in appraising the opportunity cost for alternative uses of faculty resources within each academic department. The model is also helpful in evaluating departmental requests for additional staff members and presents a better estimate of the resources needed to pursue other non-teaching goals of the university.

**WP1.6 A Cost-Effectiveness Application: The Value of Beryllium in Spacecraft,** EUGENE R. BRUSSELL, *Hughes Aircraft Company, Space Systems Division, Los Angeles, California.*

The approach and results of a cost effectiveness exercise analyzing the value of beryllium for space applications is presented. The measures of effectiveness for beryllium are analyzed in depth and comparisons are made between the measures of effectiveness of commercial and military satellites. In addition measures of effectiveness are analyzed for different types of military space missions. Beryllium possesses three characteristics that make it attractive for space use. The first is its low weight; the second is its dynamic response; and the third its structural efficiency. The problems of combining the separate measures of effectiveness based upon each of these three characteristics into a single measure are evaluated. Since the benefits are time-distributed, discounting procedures and the interest rate selection must be rationalized. Our method of predicting the total design, manufacturing and testing costs associated with this new material technology is discussed. The uncertainties still surrounding the new technology and the implications of these uncertainties for policy are explicitly faced and brought into the open. Finally, we discuss some implications for the perennial question of when or at what stage in the development of a new technology can we have confidence in a cost effectiveness analysis.

**WP1.7 Effects of Subsystem Reliability on System Cost-Effectiveness,** WILLIAM T. SMITH and EDMUND D. MORRISON, *The Boeing Company, Box 3991, Seattle, Washington.*

In the design of complex combat systems, several levels of reliability for each subsystem may be available. The problem addressed in this paper is that of selecting the most cost-effective reliability level for each subsystem. A series of mathematical models is described for solving this problem for a suitably defined system. The first two models, a Markov process and a recursively generated conditional probability tree, predict operational reliability as a function of subsystem time-to-failure distributions. This prediction accounts for interdependencies of subsystem failure distributions in the event-sequence of operations. The third model is a steepest-ascent method for finding the least-cost set of subsystem reliability alternatives that achieves a given level of system reliability. The fourth model considers a trade between individual system reliability and redundancy of systems to find the least cost value of system reliability, constrained by the requirement that a specified job be accomplished. The first three models can be included in a single IBM 7094 computer program.

**WP2.1 *Models and Operational Definitions for Comprehensive Patient Care,** CHARLES D. FLAGLE, *School of Hygiene and Public Health, The Johns Hopkins University, Baltimore, Maryland.*

Recent federal legislation in health has given impetus to the development of systems of comprehensive patient care. The implication of the term comprehensive is that a continuing, coordinating responsibility for a patient is maintained by a medical facility, perhaps a hospital, which is in turn formally related to a variety of health services other than those performed within its own walls. Three important problems are (1) the decision process for choice of appropriate health service for a patient, (2) the maintenance of appropriate records to guide the evaluation and transfer of patients, and (3) the estimation of capacity requirements for the various services. Two models have been useful for descriptive as well as analytical purposes; first a deterministic cohort survival model for estimation of the magnitude of populations to be served, divided by age, sex and other parameters relevant to morbidity and mortality. The second model is a stochastic system in which states represent discrete health facilities, each receiving an input from the others and the population at large. Use of the second model requires definitions of patient states appropriate to each type of facility, from which decision rules for transfer may be developed. These definitions are, in the case of long term illness, less related to clinical disease categories than to elements of need such as supportive nursing care, rehabilitation, and social support. Progress in developing such definitions is described.

### WP2.2 * A New Type of Compound Poisson Process with Applications to Medicine and Biology, William J. Horvath, *Mental Health Research Institute, University of Michigan, Ann Arbor, Michigan.*

Compound Poisson processes are useful in the study of problems where random events occur in a heterogeneous population. If each individual in the population had the same constant risk, and all the usual conditions of randomness were met, a simple Poisson process could be used to describe the occurrence of events. However, if the risk varies among the population according to some well defined distribution function the events will follow a compound Poisson distribution. Greenwood and Yule were the first to treat population heterogeneity in random processes in this manner. They used a Pearson Type III function to describe the risk distribution in the population and their compound Poisson function was a negative binomial distribution. However, the negative binomial can arise from other causes than those described above so that it is not possible to conclude from its occurrence whether or not a compound Poisson process is acting. Some years ago Grundy proposed the logarithmic normal distribution for a risk function and attempted to calculate tables of the resulting compound Poisson distribution. This would, however, still not have solved the difficult problem of obtaining the best fits to the data, but in any case the tables were never finished. In analyzing some recent data on the frequency of re-admissions to mental hospitals in Great Britain, it appeared that a compound Poisson might describe the observations but the negative binomial did not give an acceptable fit. Accordingly we tried the function which Grundy proposed using an optimization program developed by M. M. Flood. This program uses a search routine to find the parameters which give the minmum chi-square for the data. The fit of the data to this function was far better than to the negative binomial and suggests that this form of the compound Poisson distribution may have considerable application to many biomedical problems involving heterogeneous populations.

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**WP2.3 *Hospital Planning and Operations Research,** PETER COWAN, *Joint Unit for Planning Research, University College, London, England.*

Changing factors of hospital studies—early work concerning internal planning and layout—impact of O.R. in this area—continuing relevance of O.R. studies in refining detailed planning of hospitals—gradual evolution of wider interest—problems of growth, change and ageing in hospitals—particular need for studies of hospital location and siting—the transition from "hospital systems" to "systems of hospitals"—studies of hospital location in the United States and in Great Britain—special place of econometrics—limitations of studies—need to consider total pattern of health facilities for community—lead to need for general model of health services as a foundation for detailed studies of the pattern of hospitals.

**WP2.4 *Measures of Effectiveness for the Hospital Medication System,** RICHARD K. C. HSIEH, *U.S. Public Health Service, Baltimore, Maryland.*

The major purpose of this study was to determine the optimum system design for the inpatient medication activities in a large teaching hospital. A system was used in the experiment. Four other proposed medication systems were compared. They were evaluated in conjunction with an effectiveness model. A rating or measure of effectiveness which was derived from criteria of completeness, reliability, and efficiency was used. The most practical system was obtained through this comparison. Findings supported experimentation by the research team.

**WP3.1 Panel on: Using OR Effectively in Advertising and Marketing—Why and How,** Session Chaired by DAVID B. HERTZ, *McKinsey & Company, Inc., New York, New York* and ALBERT MADANSKY, *Market Planning Corporation, New York, New York.*

This session will be comprised of four invited papers from the panel members as follows: (1) The shortcomings of OR and the needs which must be fulfilled, if OR is to make a genuine contribution, will be presented by Dr. Banks. (2) The requirements for problem solving and quantitative aids to decision making in marketing consumer products will be discussed by Mr. Plattes. (3) and (4) Drs. Miller and Fabian will present the operations researcher's view of what has been done in the fields of advertising and marketing, respectively. They will review the various ways of approaching specific problems, why these approaches do not always seem effective or appropriate, what some of the reasons are for not being able to do more at the present time and what should be done to extend OR to the more complex issues in these fields.

**WP4.1 *The Synchronization of Traffic Signals for Minimum Delay,** JOHN A. HILLIER, *Road Research Laboratory, Ministry of Transport, London, England,* and RICHARD W. ROTHERY, *General Motors Research Laboratories, Warren, Michigan.*

In order to ascertain whether neighboring intersections can be effectively coupled on the basis of traffic behavior, observational information on vehicular platoons was collected at four sites in London, England. This information is analyzed with particular emphasis on the phasing or synchronization of neighboring intersections for minimum delay. At each of the four sites studied, arrival time data was collected at four positions downstream from the signalized intersection from which the vehicular platoons were emerging. These data give a measure of how platoons diffuse as they move from one intersection to the next. The analysis indicates that the diffusion process can be taken into account in the setting of signals. In particular, total delay in vehicle-hours per hour of green as a function of offset time is calculated, and in turn, the optimal offset time which would minimize delay is shown to be a linear function of the distance from the issuing traffic signal.

**WP4.2 * Operations Analysis for Transportation Systems Design,** E. FARNSWORTH BISBEE, *Massachusetts Institute of Technology, Cambridge, Massachusetts.*

The Northeast Corridor Transportation Project begun by the U.S. Department of Commerce raises a number of issues that have traditionally been dealt with on an ad hoc basis, if at all, in the evaluation of ground systems for regional service. One such issue recognizes the prospect of new technology for the system design and leads to the question of how best to match traveler utility and system cost within feasible design alternatives. The spectrum of operating policies and their influence on effectiveness criteria are indicated by illustration of an explicit though limited first order model with externally fixed utilization functions. Computational results based on the model are presented and discussed.

**WP4.3 * Study of Passenger Allocation and Flows for Scheduling,** J. GILLES GAGNON, *Air Canada, Place Ville Marie, Montreal 2, Quebec, Canada.*

There are frequently several different ways in which passengers may fly from any one point in Air Canada's system to any other. Passengers may choose a non-stop flight, a flight using most desirable aircraft, a flight departing or arriving at the best time and so on. It is necessary for those in charge of preparing the schedule to plan many months ahead to obtain a schedule which will answer the needs and desires of the passenger traffic. The objectives of the Passenger Allocation Model are to allocate to the various flights offered the number of passengers using them at a time "*n*" months ahead. The factors considered are: (1) Frequency of the flights between two points. (2) Times of arrival and departure. (3) Number of enroute stops. (4) Type of aircraft. (5) Type of flight (direct or connection). (6) Capacity available. This paper describes how the model has been designed to allow for these factors, and enumerates the information required to set up the primary and secondary inputs of the model. It then illustrates some particular results which have been produced and compares these with actuals. Finally, it indicates the place of the model in a long range planning system.

**WP4.4 * Freigher Scheduling Model,** C. A. OLSON, E. E. SORENSEN and W. J. SULLIVAN, *Matson Research Corporation, 215 Market Street, San Francisco, California.*

A model of Matson Navigation Company's freighter movements has been created to generate ship schedules between the West Coast and Hawaii for three-month periods. The model describes the general characteristics of the ships and port facilities; it considers the West Coast as three port areas. Cargo build up and ship timing are based on average values; no stochastic variables are used. Input to a run includes cargo forecasts and initial positions of the ships in the fleet. Decisions on ship movements are made chronologically on the basis of estimated voyage profit and service requirements. Twelve cargo types and six port pairs are used. Of 72 possible cargo-port pair combinations, 29 actually occur. Programming is in GPSS-3 for the IBM 7094. IBM 1401 programs were written to facilitate entry of data and also to tabulate the output in a different format for easier analysis of results. A three-month period, in one-hour increments, takes six minutes to run on the 7094. The model utilizes the computer to arrive at the most profitable schedules consistent with certain rules laid down by management. The model has been used for planning in the current year and studying requirements for the future fleet. It offers the following advantages: computational accuracy in production of medium-range schedules; incorporation of profit criteria in many schedule decisions; speed of testing several alternatives; and consequently, more responsive and satisfactory fleet scheduling than could be done by hand.

**WP4.5 * Interstation Spacings for Line-Haul Passenger Transportation,** VUKAN R. VUCHIC, *The Towne School of Civil and Mechanical Engineering, University of Pennsylvania, Philadelphia, Pennsylvania.*

Population of an area commutes to one central point. The assumption is that the decision to build a passenger transportation line with discrete operation (e.g. rapid transit) to serve this area has been made. The number and locations of stations at which the commuters board the vehicles for their travel to the central terminus are to be determined so that the aggregate travel time of all passengers—from their origins to the destination—is minimal. Total passenger travel time from origins to the stations on the system have been computed for several different sets of parameters. The optimal station locations, derived either by the partial differentiation of the total time with respect to the locations or by a dynamic programming procedure, satisfy a set of simultaneous difference equations. In general, the spacings are functions of the ratio between the number of passengers traveling on the train and those wanting to board or alight. Algorithms for numerical and graphical solutions have been derived for the analyzed sets of parameters.

**WP5.1 An Ordering Policy for Repairable Stock Items,** STEPHEN G. ALLEN and D. A. D'ESOPO, *Stanford Research Institute, Menlo Park, California.*

It is assume that an inventory item which fails in service is either repairable (with probability $p$) or is not repairable (with probability $1-p$). It is also assumed that failure is generated by a Poisson process, and that a failed item will be reparied if possible. When $p<1$, the serviceable stock must be replenished from time to time by orders for new supplies. An order policy of the $(s, S)$ type is determined which minimizes the cost per unit time associated with the expected number of orders placed, inventory, and units short. The derivation of expressions for expected inventory and shortages is of particular interest for the case $0<p<1$ in contrast to the case $p=0$ (no repair possible) or the case $p=1$ (100% repairability). This is due to the fact that stock on hand can increase with positive probability at any time between successive deliveries of new supplies. Numerical examples conclude the paper.

**WP5.2 The One-Period Production and Inventory Control Problem of a Multi-Commodity System with Probabilistic Demand and Interacting Set-Up Cost,** B. D. SIVAZLIAN, *Department of Industrial and Systems Engineering, The University of Florida, Gainesville, Florida.*

The characteristics of a multi-product production and inventory system with probabilistic demand and interdependency in the set-up cost are studied over a single period, and optimal ordering policies for inventory replenishment are derived. Three cost elements are assumed to affect the operation of the system: a production cost, a holding cost and a penalty cost. The fixed component of the production cost, i.e. the set-up cost, will, in general, depend on whether an individual ordering policy, a partial joint ordering policy or a total joint ordering policy from production is used. In general, for an $n$-commodity system, one can define the optimal strategies over a policy space in $E^n$. This concept is illustrated for $n=2$. Thus, depending on the initial stock level of the items either of the four following alternatives is possible: a) produce the first item only; b) produce the second item only; c) produce both items simultaneously; d) do not produce anything. The general problem is clearly equivalent to a multi-commodity, multi-warehouse system supplied by a single source.

**WP5.3 The Machine Loading Problem in Production Systems,** DAVID ROTHENBERG, *Industrial Mathematics, Inc.,* JOHN FOX, *W. R. Grace & Co.,* EDWARD A. TOMESKI and GEORGE STEPHENSON, *Systems and Management Innovation Inc., 2 West 45th Street, New York, New York.*

The Machine Loading Problem is a production problem formulated in mathematical terms. Practically, it is the problem of scheduling production on a set of machines for a production period of specified length where any machine may be used in the production of a variety of products, and production of any product may require a variety of machines. Scheduling must be made in consideration of inventory requirements, availability of materials, varying (seasonal) demand, and all relevant cost factors: materials, labor (straight and overtime), overhead, set-up costs, etc. The problem, of course, is to schedule production and inventory for maximum profit (minimum cost) from known production costs and predicted sales and inventory requirements. The model to be discussed does determine optimal lot sizes for each of $p$ products made on $m$ machines where demand is specified for each of several future time periods.

**WP5.4 The Effect of Reducing Leadtime on Inventory Levels—Simulation Analysis,** DONALD GROSS, *The George Washington University, Washington, D.C.,* and A. SORIANO, *Institute for Defense Analyses, Arlington, Virginia.*

The allowed safety stock level reduction and accompanying reduction in average on-shelf inventory level are evaluated, for prescribed system performance requirements, as a function of mean leadtime reduction. The general simulation technique developed for this purpose allows the treatment of the $(s,S)$ periodic review inventory problem with both demands and leadtime being stochastic. Some results obtained for a military supply system, where the reduction in leadtime is achieved by resorting to airlift rather then sealift, are presented. In addition, generalizations as to the effects of certain parameters on the reductions allowable for general situations are given. Finally, a simplified means of predicting these effects by an empirical method is indicated.

**WP5.5 Economic Selection of Inspection Criteria for Item Inspection for Defects in a Multistage Production Process,** LYNWOOD A. JOHNSON *Department of Industrial Engineering, Georgia Institute of Technology, Atlanta, Georgia.*

For multistage systems wherein items must be processed sequentially through a series of production operations and where there is a maximum number of defects allowed a completed unit, there may exist the problem of determining acceptance criteria for inspection between production stages. The hypothesis that an economic gain could be realized from tightening the specifications (i.e., rejecting an item with less than the allowable number of defects) for inprocess inspection is examined with respect to two problem environments: (1) a manufacturer producing to satisfy a fixed production quota, and (2) a manufacturer producing until he exhausts fixed levels of resource availability. Under specific assumptions regarding the disposition of rejected product, a dynamic programming model is formulated for each problem. Analysis of these models indicate that artificially severe specification limits should be considered and that dynamic programming methods can be utilized to determine the most economic limits.

**WP5.6 Unified Production Planning and Control,** ROBERT W. BLANNING and RICHARD J. SWERSEY, *Management Science Center, University of Pennsylvania, Philadelphia, Pennsylvania.*

A dichotomy between the production planning and control functions is caused by the different attitudes, backgrounds, and goals of the personnel involved. This often results in a failure of implementation of analytical production models. Frequently, the management information system (MIFS) used by management for production control can also be used by the analyst for production planning. The MIFS should be designed around a model of the system in order to provide information which will improve production performance through better decisions, and not merely report available data. This same model may be used in production planning via analysis or simulation. We applied these ideas on an industrial research project for a manufacturer who wanted an economic rationale for allocating limited inventory capacity to safety stock and for determining optimal stocking levels. We solved the problem by simulating with the MIFS. This technique successfully welded the planning and control functions of the manufacturer; some of our results were implemented before the final report was written.

**WP5.7 Optimization of an Inventory by Regularly Adjusting the Deterministic Component of the Stochastic Input Process,** HANS KASPAR, *Rocketdyne, North American Aviation, Inc., Canoga Park, California.*

A major problem which arises when dealing with costly purchased items in support of a final product is the determination of an adequate inventory. Control of this type of inventory requires the monitoring of the demands on parts to detect any change in requirements. Any significant shift must be met by adjusting the delivery dates of incoming items. These specified times are adjusted on the basis of estimated inventory levels by statistically forecasting the withdrawals and replenishings of purchased parts. The inventory can be described by the difference between a compound input process and a compound output process of purchased parts with known deterministic and random components. Several criteria for adjusting specified delivery times to insure optimum inventory levels are developed.

### WP5.8 Optimal Continuous Review Policies for Two Product Inventory Systems with Joint Setup Costs, EDWARD IGNALL, *Columbia University, New York, New York.*

Optimal ordering policies for two product inventory systems in which the inventory position is reviewed continuously are sought. Demands are assumed to arrive according to two independent Poisson processes. The setup cost incurred when both products are ordered simultaneously is assumed to be less than double that incurred when only one is ordered. Holding cost is linear in inventory. It was hoped that the optimal policy would be simple in form: Unfortunately, even for a symmetric no-runout case, there are some parameter values for which a difficult to implement policy is optimal. The parameter space is explored by using the "test quantities" of Markov Renewal Programming.

### WP5.9 A Reparable Inventory System with Continuous Repair, D. A. SCHRADY, *Naval Postgraduate School, Monterey, California.*

A reparable item is repaired after failure. The reparable inventory system has an inventory of ready-for-issue items (RFI) and an inventory of non-ready-for-issue (NRFI) item carcasses. Since some failed items are scrapped and not repaired, it is necessary to procure new items from time to time. The RFI inventory thus has two sources, procurement and repair, with different costs and lead-times. This paper treats a probabilistic reparable inventory system and determines jointly the optimal procurement quantity and the optimal repair rate.

### TA1.1 Panel on: Cost Effectiveness Impact of DOD Directive 3200.9, Session Chaired by E. S. WINLUND, *Douglas Aircraft Co., Santa Monica, California.*

DOD Directive 3200.9 calls for selection between system alternatives on the basis of expected operational cost-effectiveness (CE), which in turn implies system and component development on the same basis. Directive 4100.35 calls for logistic planning and procurement on the same basis. Major contracts have been awarded on the basis of government and contractor CE analyses, though almost none via CE incentives. Some contractors are developing the use of CE analysis for system and hardware development, meaning day-to-day decisions based on CE. The use of CE incentives should accelerate this trend. In order to review the chain impact of 3200.9 from source to contractor implementation, we are fortunate to have panel representatives from DOD-ODDR&E, Air Force Systems Command ESD, DOD-I&L Procurement Management, and C5A contractor Lockheed-Georgia. Each will respond to these questions directed to his organization: (1) What are your objectives leading to use of CE analysis? (2) What have you accomplished to date concerning use of CE? (3) What are your principal needs and problems concerning CE? (4) What steps do you expect to take in the next few years? (5) What other steps do you anticipate in the next 5 to 15 years? Each panelist will have responded in writing prior to the Meeting, with additional interchanges to resolve any semantic misunderstandings. These responses, together with a summary of areas of agreement and recommendation, will be made available as a paper. At the Meeting the panelists will respond to the same questions, but in greater depth and perhaps more controversially.

**TA2.1 * Banking Research: Prospects and Problems,** Frederick S. Hammer, *Federal Deposit Insurance Corporation, 550 17th Street, N.W., Washington, D.C.*

The upheavals in methodology which have characterized economic research in the post-war era have in recent years begun to permeate the banking industry. The results of preliminary applications have at times proven quite fruitful. Extrapolating from these successes, (overly?) optimistic proponents of the new techniques occasionally seem to argue that research progress will advance at an accelerating pace into the infinite future. Nonetheless, formidable difficulties must be resolved if future efforts are to be successful. The paper outlines the major research areas in banking, reviews research progress to date, attempts to indicate the ways in which O.R. techniques may come to be applied in banking, and suggests some of the problems to be encountered along the way.

**TA2.2 * Cost Structure of Banks,** Irwin Miller, *Arthur D. Little, Inc., 35 Acorn Park, Cambridge, Massachusetts,* and Irving Plotkin, *Massachusetts Institute of Technology, Cambridge, Massachusetts.*

A pilot study was performed under the auspices of the Federal Deposit Insurance Corporation to provide guidelines for a full-scale study. In the course of this study we were able to construct an equation with fairly good cost predictive abilities. A full-scale study is now in progress for the FDIC. This study features extensive use of information concerning flow variables (such as number of checks cleared, number of new deposits, etc.) as well as stock variables (such as total value of time savings deposits, etc.). In our analysis of the results we propose to reduce colinearities by including in the final model residuals (rather than the values of the variables themselves) after regressing each independent variable on the asset size of the bank.

**TA2.3 * A Model of Consumer Banking Behavior,** Robert L. Kramer, *Bankers Trust Company, 16 Wall Street, New York, New York.*

Banking, as an industry, was slow to adopt the techniques of Operations Research. It has been just as slow to delve into market research. Thus, applications of O.R. to bank market research problems are rare indeed. One such model—perhaps the first—is discussed here. Consumers may be classified according to their demographic and socio-economic characteristics. (This procedure may be useful in itself: a number of banks collect and use such "customer profile" data.) A number of hypotheses can be advanced, based on this type of population analysis. For example, one would assume that a "high income" person is more likely to open a regular checking account than a "low income" person. Unfortunately, few if any efforts have been made to quantify or even validate such propositions. A mathematical model is presented which attempts to predict, on the basis of selected demographic and socio-economic variables, specific consumer banking behavior such as the types of accounts that will be held, the size and fluctuations of balances, and the particular institution(s) which will be selected. Additional potential applications and implications of this research are discussed.

### TA2.4 * An Adaptive Model for Investment Management, JERRY A. POGUE, *Carnegie Institute of Technology, Pittsburgh, Pennsylvania.*

An adaptive inter-temporal investment management model is developed to maximize the return on invested funds over an $N$ period time horizon, consistent with a specified level of risk. The inter-temporal nature of the model allows for the planned switching of funds between securities at various decision points within the time horizon. The model takes into explicit consideration the transactions' costs involved in moving from an initial non-optimal portfolio to a portfolio which is more efficient in terms of revised expectations. The portfolio management segment of the investment model can be considered as a multi-period generalization of the Markowitz portfolio selection model. An efficient frontier is generated which provides a trade-off between return over the time horizon (after transactions' costs), and the risk associated with the level of return. The remaining segments of the investment management model are concerned with adaptively providing the required security input data for the portfolio management phase. Multivariate statistical techniques are employed to forecast adaptively various determinants of security price. A time series valuation model is then applied to each security to predict price levels during each of the $N$ periods of the planning horizon. The performance of the investment management model is compared with the actual performance of the common stock portions of pension funds, with the performance of naively selected portfolios, and with mutual funds.

### TA3.1 * Analysis of Selected Operations Problems in an Automated Library System, NORM MEISE, *United Aircraft Corporate Systems Center, Farmington, Connecticut.*

As part of a conceptual design of an automated national library system, an analysis was made of selected problems dealing with the structure and operating policies of such a system. This paper presents a summary of this analysis. The following topics are covered briefly: The need for an automated system, an outline of a conceptual design, a proposed policy for determining the size and content of the collections of local libraries served by the automated system and the nature of the services provided by the system. Emphasis will be placed on the application of a principle that the author calls "diminishing cumulative utility."

**TA3.2 * The Effect of Response Time upon Utilization of an Information Retrieval System—A Simulation,** ROBERT M. HAYES, *Institute of Library Research, University of California, Los Angeles, California.*

A simulation program is presented which considers the effect of response time upon the utilization of a multiple node information system. Specific examples of such systems are presented. They include: 1) information networks, 2) library systems, 3) multi-level files. The simulation characterizes users (in terms of their information requirements and expectations), information services, and nodes or locations at which those services are available. The effects of various allocations of resources to different levels of service, different locations, and different response times can be demonstrated, particularly in terms of the levels and kinds of utilization.

**TA3.3 * An Algebraic Model for the Processing of Formatted Files,** W. D. FRAZER, *International Business Machines Corporation, Thomas J. Watson Research Center, Yorktown Heights, New York.*

Most existing specifications for processing of formatted files invoke, either directly or indirectly, the Boolean Algebra of sets. In many cases, however, the algebraic structure imposed by retrieval requirements is much more general than the structure of Boolean Algebra, and the latter is but one of many systems whose elements may, for processing purposes, be used to represent the items of a file. A general model for the algebraic structure imposed by the processing requirements of a large class of formatted files of all types will be given, together with examples of commonly encountered files which fit the model. It will be shown that certain kinds of queries which seem "natural" linguistically are not "natural" algebraically, in some systems, and thus turn out to be somewhat clumsy to implement. Finally, some examples of algebraic systems other than the Boolean Algebra of sets will be shown to fit the model and thus to provide acceptable representations for the types of files considered.

**TA3.4 * A Literature Search Model,** FERDINAND F. LEIMKUHLER, *School of Industrial Engineering, Purdue University, Lafayette, Indiana.*

A principle of sequential optimization in search theory distributes the search effort at each stage so as to maximize the probability of target detection with the effort expended thus far. (J. M. Dobbie, Search Theory: A Sequential Approach, *Nav. Res. Log. Qtly.*, X, 4, p. 332, (1963).) As a special application of this principle, literature files should be organized for search and retrieval operations in decreasing order of the probability that an item will yield the information sought. Complete ordering in this manner may not be feasible and it is proposed that the files be partially ordered in zones of uniform probability density with some loss in search efficiency. A model for assessing the relative efficiency of partial ordering is developed and used to determine optimal zone lengths under assumed target distribution pattern. In this way, tradeoffs between file organization effort and search effort can be meaningfully evaluated. It is proposed that a useful target distribution function for research literature has the form: $f(x)=\log(1+\beta x)/\log(1+\beta)$, where the parameter $\beta$ can be related empirically to the characteristics of a literature field and to the completeness of the literature file. This function is used to demonstrate the application of the file organization model to search and retrieval operations.

### TA3.5 *Measures for the Comparison of Information Retrieval Systems, and the Normalized Sliding Ratio, Stephen Pollock. *Naval Postgraduate School, Monterey, California.*

A definite need exists for an absolute and uniform means of comparison and evaluation of certain characteristics of various information retrieval systems. This paper is concerned only with the system's ability to satisfy queries—the effort and time used, and their relative costs, are not considered. Some past procedures that have been used are reviewed and discussed, along with some of the difficulties that arise when these procedures are followed. Taking liberties hopefully allowed to those unfamiliar with the mystique and jargon of the growing discipline of Information Retrieval, we present some desirable characteristics for a meaningful measure of effectiveness. We then introduce one such measure that may be used to compare the retrieval capabilities of a large variety of systems. This measure, called the "Normalized Sliding Ratio", has a relation to the classical recall and precision ratios, and may be looked on as a generalization of them.

### TA4.1 Space Station Mission Simulation Mathematical Model, Travis E. Peace, *General Dynamics Corporation, Fort Worth, Texas.*

A detailed mathematical model and attendant computer program to provide a managerial tool for efficient planning and implementation of the Manned Orbital Research Laboratory concept was developed under contract NAS1-5874 for the National Aeronautics and Space Administration's Langley Research Center. The model was designed to treat all major operational aspects of a space station system in the preliminary design phase. It can be used to evaluate the responsiveness of the system to various mixes of missions, experiments, crew skills, and logistics systems and employs such effectiveness measures as mission duration, logistics requirements, costs, resource use efficiencies, and special effectiveness indices. The model program plan matches the program of an actual space station. That is, a program plan is developed and then simulated as though it were actually being accomplished. The model is designed so that it can be expanded in accuracy and detail and employed for mission planning and control during the station operational phase, where live inputs could replace the simulated data. Typical results are shown demonstrating the effectiveness of the model, and its scope of utilization.

### TA4.2 A Computer Model for Scheduling Crew Activities for Long-Duration Space Missions, James G. Srygley, *Fort Worth Division of General Dynamics, Operations Research, Fort Worth, Texas.*

For space missions involving concepts such as manned space stations, semipermanent lunar bases, and manned planetary flybys the mission duration may range from less than 90 days to several years. Considering the trade-offs involved in level of scheduling detail, degree of accuracy in input data available, and optimum use of existing computer systems it becomes apparent that a scheduling concept is needed which is entirely different from that of current scheduling models for short duration missions. A generalized scheduling methodology, based upon scheduling by discrete time intervals (8 hour shifts, 24 hour periods, etc.) is developed and presented in this paper. The level of scheduling detail can be varied by changing the scheduling interval, allowing a balance between scheduling detail, duration of mission, accuracy of input data, and machine limitations to be reached for any conceivable space mission. A general scheduling model based upon this concept has been programmed and used to schedule for missions with durations of well over one year. A specific version of this scheduling model is used in the Space Station Mission Simulation Mathematical Model developed for NASA Langley Research Center. Results using the data base for this model are presented.

**TA4.3 Experiment Selection for Manned Space Flights,** JOHN K. HANCOCK, *Martin Marietta Corporation, P. O. Box 179, Denver, Colorado.*

Selection problems are common in the field of management science. Many varied approaches have been advanced for the solution of these problems. Often they can be placed in an integer linear programming format with zero-one variables, and solved using mathematical techniques. Two difficulties arise from a linear programming approach, particularly when the algorithm selected is to be programmed for computer solution. The first difficulty is simply the operational awkwardness of these algorithms, with the accompanying difficulty in programming them. The second difficulty is the criticism which has been leveled at any exact solution based on value assignments which are not exact, and in many cases are only crude approximations. In studying the problem of experiment grouping for space flights, a technique has been developed which solves the linear programming form of the selection problem while avoiding the two difficulties above. The resulting selections compare favorably with those from other independent approaches to the problem. The paper summarizes the algorithm and illustrates its use on selection problems.

**TA4.4 A Research and Development Cost Spreading Technique,** MELVIN E. CAPEHART, *Martin Company, Denver, Colorado.*

Space systems development costs can be divided into the cost categories of Research, Engineering, Hardware and Booster Procurement, Ground Support and Facilities, and System Integration. The ideal situation is to have cost data for the above categories, lay out a development schedule, and calculate the yearly costs of the system. This is not practical for preliminary studies of projections of space activities extending into the 1970's and 1980's. There are in existence many algorithms that generate estimated total system costs based on estimated system weights, data transmission rates, experiment weights, etc. This paper presents a technique for generating funding profiles for space research and development programs using only the total estimated cost and total development time. The methodology for development of the technique was to fit a least mean squares quartic polynomial to Gemini cost data. The equation was then generalized and normalized. Examples comparing the results using this technique and results of more detailed analyses are presented for the Lunar Extended Stay—Apollo, the Apollo Logistic Support System, and a Mars Excursion Model. These examples show that the quartic polynomial can be expected to yield reasonably good estimates to the manner in which space program research and development costs are spread over a period of time.

**TA4.5 Application of Linear Programming Techniques to Space System Operations Scheduling,** SIDNEY I. FIRSTMAN and RUSSELL A. WELKER, *Aerospace Effectiveness Department, Planning Research Corporation, 1100 Glendon Avenue, Los Angeles, California.*

The scheduling of several classes of space systems operations is efficiently accomplished using linear programming techniques. This applications-oriented paper describes two such scheduling problems: integration of prelaunch operations requirements into an effective schedule and mission operations planning for manned space flight. Each of these problems is characterized by the linearity of most scheduling requirements and constraints. A second similarity is the strong likelihood of no feasible solution existing for the initial set of requirements and constraints—with numerous planning statements needing modification to achieve a feasible solution. Planning requirements and constraints of several priorities and extremely high dimensionality are other characteristics shared by the two problems. This paper describes and illustrates the types of constraints and requirements characteristic of each problem. Also presented are methods used to resolve difficulties arising from the characteristics noted, while using linear programming techniques in the search for feasible schedules. A departure from linear forms is required to determine a preferred solution for the launch pad scheduling problem; this is described briefly, as are the possible objective functions and relatively straightforward optimization process for the mission planning application.

**TA4.6 A Quasi-Optimal Scheduler for a Ground Radar Tracking Satellites at High Rates,** D. LOBEL, *RCA, Moorestown, New Jersey,* T. J. SCHAEFER, and M. I. STRIEB, *Kettelle Associates, Inc., Paoli, Pennsylvania.*

The problems of satellite bookkeeping by means of continual observation from a limited number of tracking radars becomes increasingly complex as the population of man-made orbiting objects grows with time. For example, a given tracking radar site, faced with tasking imposed by a central controller, soon finds that a manual track scheduling operation is both inefficient and time-consuming. To alleviate the radar assignment burden and permit an approach to an optimal procedure, a digital computer program (SASSI) has been developed. SASSI makes use of the dynamic programming concepts of Bellman to overcome the storage problem presented by a permutational approach to optimal scheduling. In producing its assignment it takes into account such constraints as the differences in satellite priorities, varying demands for track duration, time-in-view, and lock-on probability of the radar.

**TA4.7 Operations Research Techniques in Politics,** MIKLOS WASS DECZEGE, *Wass Associates, 617 Central Trust Tower, Cincinnati, Ohio.*

Fundamental principles of voter information systems and campaign management systems are discussed. The concept of "Voter Publics:" is developed. Approaches for identifying voter publics including the use of surveys and census tracts are covered. The report develops basic concepts of social area analysis and its implication in a political campaign. The campaign systems used by Robert Taft, Jr. and the voter information system developed for the Hamilton County Republican party and their effects on political decision making are also discussed.

### TA4.8 Optimum Operations of Multi-Reservoir Water Supply System,

REUVEN AMIR, *The Service Bureau Corporation, 2450 Watson Court, Palo Alto, California.*

The system analyzed consists of a number of interconnected reservoirs, each one receiving random inflows at successive stages; before each set of simultaneous inflows, releases are made for consumption, and water may be transferred among the reservoirs in the system. The total demand for water at each stage is known; it may exceed the supply, causing a loss which is assumed to be a convex, increasing function of the shortage. Also, a cost is incurred in conveying water through the system. The objective is to determine an optimum operating policy, namely, releases at each stage as function of storage levels leading to a minimum total cost (shortage and conveyance) over a given number of stages. The properties of the optimum policy are investigated analytically, using the dynamic programming recursive equation. Results similar to those obtained by Massé and Géssford and Karlin for single reservoir systems are derived for the multi-reservoir case under various assumptions, such as zero transfer costs, no transfer constraints, piecewise linear cost functions, symmetric cost and probability functions, and others. The results consist of information about sets of the state variable over which the optimum policy is either known or constant and can be determined without recourse to a full numerical solution, and of establishing certain monotone properties of the optimum policy.

### TA4.9 Optimal Control of Wildland Fires,

ALAN W. MCMASTERS, *Department of Operations Analysis, Naval Postgraduate School, Monterey, California.*

The wildland fire control problem is analyzed using Pontryagin's maximum principle for a generalized form of the Parks-Jewell fire growth model. This form relaxes the restrictions, assumed in previous studies, that suppression forces cause a deceleration of the fire's growth which is proportional to the force size and independent of time. As a consequence, the control effort derived describes the overall integrated efforts of an initial attack suppression force which would minimize the total fire costs. Included in the analysis is the interesting subset of problems where time of control and size of the fire at control are specified. The nature of the optimal control effort is examined for several different forms of the objective function. The problem of reinforcements is also briefly considered.

### TA5.1 Finite, Closed-Loop Queueing Systems with Time Lags,

MORTON POSNER and B. BERNHOLTZ, *Department of Industrial Engineering, University of Toronto, Toronto 5, Canada.*

Consider a finite, closed-loop queuing system in which $m$ units move cyclically among $N$ service stations $1, 2, \cdots, N$. A unit which completes service at station $i$ $(i=1, 2, \cdots, N)$ moves to station $i+1$ (mod $N$), where it either commences service immediately if there is a server available, or joins a queue to await service. The time taken for a unit to move from station $i$ to station $i+1$ (mod $N$) is assumed to be a random variable with distribution function $G_i(\cdot)$. The service times at station $i$ are assumed to be independent, exponentially distributed random variables with means which may be arbitrary functions of the number of units at that station. The process is investigated by introducing certain supplementary variables, namely the positions of the units enroute between stations measured in time units, resulting in a continuous time Markov process with a combination of discrete and continuous states, The integro-partial differential equations for the state variables are derived, and the steady state solution is determined. The results are then compared with known results for the system with no time lags. The cyclic queuing model is then generalized to a network of $N$ service stations with time lags. Thus, a unit which completes service at station i moves to station $j$ ($i, j=1, 2, \cdots, N$) with probability $C_{ij}$ ($\sum_{j=1}^{n} C_{ij}=1$, $i=1, 2, \cdots, N$), and the time taken to move from station $i$ to station $j$ is a random variable with distribution function $G_{ij}(\cdot)$. This process is also investigated using the supplementary variable technique, and new results are obtained, both for this system, and the equivalent system with no time lags.

### TA5.2 Solution of M/G/1 AND GI/M/1 Finite Queueing Problems by Graphical Means,

GARY E. WHITEHOUSE, *Department of Industrial Engineering, Lehigh University, Bethelehem, Pennsylvania.*

Using Kendall's well-known concept of imbedded Markov chains, M/G/1 and GI/M/1 finite queueing problems can be represented as a GERT (Graphical Evaluation and Review Technique) network. A repairman problem is considered as an example of the technique. By solving the repairman network in various ways the following information is available. The moment generating function of such things as (a) the time to plant failure, (b) the duration of failure, (c) the busy period and idle time of the service facility, (d) the number of machines failing before complete failure of the plant, and (e) the time to regeneration given the system does not fail, can be found. Steady state probabilities, and such probabilities as the probability of a plant failure before the system returns to the state of no machine failures given you are presently in a particular state can also be found from the graphical representation of the repairman problem. The approach presented can be applied to any finite queueing problem for which an imbedded Markov chain can be found.

### TA5.3 A Numerical Method for Constructing Tables for Transition Probabilities and Related Measures for Some Infinite Queueing Systems,

U. NARAYAN BHAT and STUART H. MANN, *Operations Research Group, Case Institute of Technology, Cleveland, Ohio.*

Queueing problems are being solved mostly under steady state conditions. As it is this is not a satisfactory situation. The cause for this state of affairs seems to be the complexity of the expressions encountered in the study of transient behavior. Further, there does not seem to exist a comprehensive table for the transition probabilities even in some of the simple queueing systems. To remedy this, the authors have undertaken to study the following single server, infinite source queueing systems (1) Poisson arrival, constant service, (2) Poisson arrival, $k$-Erlangian service ($k=1, 2 \cdots$) (3) Deterministic arrival, negative exponential service and (4) $k$-Erlangian arrival, negative exponential service. Using some of the explicit expressions derived by U. Narayan Bhat and N. U. Prabhu (*Operations Research* **11**, *380* and *Sankhya* A25, *281*) and Bhat (unpublished), transition probabilities and related measures such as transient expected queue length, etc. and other illustrative graphs are obtained for the systems mentioned above. The numerical method used is that of considering the explicit expressions in terms of modified power series involving the parameters of the process.

### TA5.4 Queues with Semi-Markovian Arrivals, ERHAN ÇINLAR, *Northwestern University, Evanston, Illinois.*

A single server queueing system with negative exponentially distributed service times is considered. There are a finite number of types of customers, and the types of successive arrivals form a Markov chain. Further, the $n^{\text{th}}$ interarrival time has a distribution function which may depend on the types of the $n^{\text{th}}$ and the $(n-1)^{\text{th}}$ arrivals. The queue size process, waiting times, and the busy period process are investigated. The queue size process is studied both in continuous time and as imbedded at epochs of arrivals. It is shown that the queue reaches an equilibrium if and only if $\lim_{n\to\infty} E[Y_n]$ is greater than the mean service time, where $Y_n$ is the $n^{\text{th}}$ interarrival time. Transient behavior of the processes of interest is characterized and the limiting probabilities are computed. Queues of this type arise in traffic theory, (when the distance between vehicles depend on the types of both the leading and the following vehicles), in the theory of queueing networks, (when the output of one queue becomes the input to the next queue), and in general when the interarrival times are correlated but are such that they are mutually conditionally independent given the realization of some Markov chain with finitely many states.

### TA5.5 An Analytical Study of a Monte Carlo Simulation Program to Solve the General Queue Length Problem for Several Service Stations, DAVID P. REILLY, *General Electric Company, Re-Entry Systems Dept., Philadelphia, Pennsylvania.*

This paper presents an analytical study of the efficiency and effectiveness of a Monte Carlo Simulation procedure as it was applied to the multi-service station problem. The general problem of determining the optimum number of service stations that should be maintained for various combinations of fixed cost for such facilities for variable cost of downtime per unit time on each of the $M$ customers that are to be serviced; given the moments and the distributional form of the production and repair times, is a classic in Operation's Research technology. A computer program was written to handle the simulations in FORTRAN II. It was executed for various amounts of Total Simulated Time varying from 2,000 hours to 160,000 hours. This simulation generated the expectations of Total Cost based upon both Fixed and Variable Costs and thus allowed selection of an optimum combination which, as it turned out due to the specific weighting that was applied, was essentially two-fold (3 or 4). This points out markedly the effect of Bayes'

Decision Making and in general that the subjective cost estimates are quite significant in the ultimate decision.

**TA5.6 Work Conserving Priorities,** Ronald W. Wolff, *Department of Industrial Engineering and Operations Research, University of California, Berkeley, California.*

In certain situations, it is reasonable to assume that priority rules do not affect the time spent in service by any job. For queueing models where this is assumed, the priority rules are said to be *work conserving.* This concept unifies and simplifies the analysis of a variety of priority queues. This will be demonstrated for the nonpreemptive and preemptive resume M/G/1 cases. Results will also be presented which are valid for Gl/G/1 queues.

**TA5.7 A Class of Tests of Hypotheses of Components of Variance,** Sol Haberman, *Applied Physics Laboratory, The Johns Hopkins University, 8621 Georgia Avenue, Silver Spring, Maryland.*

When outcomes of experimental trials can be stated in discrete steps such as success, partial success, partial failure or failure, a new class of tests of hypotheses is available which determine how greatly the outcomes of the experiment are affected by changing the independent variable levels one at a time, two at a time and so forth. By making comparisons in different directions in the table of outcomes, joint effects can be measured so that the extent to which variables support or oppose each other in their effects on the outcomes is more explicit. Components of variance may be studied which have hitherto been locked in the structure of the table. No mathematical model is fitted in the least squares sense. The central assumption used is that the probabilities of success and failure are constant over all of the cells. A recently published experiment, analyzed by standard methods will be reexamined using these tests.

**TA5.8 On the Evaluation of a Class of Cumulative Probability Integrals Containing Bessel Function Products Using Generating Functions of Orthogonal Polynomials,** Aaron N. Silver, *The Martin Company, Systems Analysis, P. O. Box 179, Denver, Colorado.*

The analysis of statistical noise problems in multi-channel adaptive communications and data transmission systems has received wide attention by numerous authors. Assuming that the noise corresponds to a very large number of extremely small random displacements, the analytical procedure yields integrals which are closely associated with classical random walk problems as formulated by Kluyver. Specifically, these integrals also arise in the computation of the cumulative probability of the envelope of one or more sinusoidal carriers or sub-carriers immersed in additive white Gaussian noise, i.e., the Nakagami-Rice probability density. The primary result of this paper is the development of a methodology for obtaining closed-form solutions to these integrals by the use of known generating functions of orthogonal polynomials, which are related to the hypergeometric series expansion of the Bessel function products. As an application of the technique developed, an illustrative numerical example is presented relative to a binary data transmission system.

**TP1.1 *The Theory and Application of Metagames,** NIGEL HOWARD, *University of Pennsylvania, Philadelphia, Pennsylvania.*

The theory of metagames is predictive rather than normative, treating how games will be played as opposed to prescribing the best way of playing. Strategy choices are therefore treated as interdependent on the assumption the players may perceive their choices this way even when they are physically dependent. The theory treats ordinal values only, so mixed strategies are not allowed. Expanding a game such as the Prisoner's Dilemma to show each Red choice as a function of Blue's choice gives a Red-Metagame. A further expansion to show Blue's choices as a function of the Red-Metagame is a Blue-Red metagame. An example is discussed which has three equilibria, called meta-equlibria. A further Red-Blue-Red metagame would have over four million columns, but a theorem shows that however much further we go in this process of expanding the game no further meta-equilibria will be found: all meta-equilibria are found after n expansions of an n-person game. Predictions are possible for stable outcomes, which must be symmetric equilibria. These are defined and examples discussed relating to the Cuban missile crisis, the Vietnam conflict and the process of nuclear proliferation. Prediction models must be tested and the results of controlled experiments are presented which have so far verified the author's assertions.

**TP1.2 *An Error Analysis of Range-Only Location and Tracking Systems,** PATRICK J. STEEN and HOWARD EISNER, *Operations Research Incorporated, Silver Spring, Maryland.*

In support of many military search and data collection operations, it is necessary to be able to locate and track friendly or unfriendly platforms, such as ships, aircraft, buoys, balloons, etc. A generalized error analysis model of a class of range-only location and tracking systems has been developed, programmed, and exercised. This paper presents the results of the application of this model to the location and tracking of remote moving platforms by a satellite system. The error analysis, which is driven by simulating the motion of the measuring system, provides platform location estimates based upon uncertainties in the satellite position, platform altitude, range measurements, time tagging and platform motion between range measurements. Distributions of platform location are plotted, parametric in platform velocity, distance from the satellite ground track, angle between lines of position, and time between range measurements. The sensitivity of location errors to component source errors is explored as is the effect of the location error on the velocity estimates. The model also considers range measurement coverage effects based upon range, look angle, antenna patterns, carrier to noise ratios, and line-of-sight limitations and is equally well applicable to location and tracking by aircraft and surface systems.

**TP1.3 *Reliability-Maintainability Model of a Complex System,** WILLIAM H. COOK, *Operations Research Incorporated, Silver Spring, Maryland.*

A mathematical model is described which formulates the reliability of a complex electro-mechanical system for a wide range of operating conditions and maintenance procedures This model, which has an analytic structure, is programmed for use with high-speed computers. The model is able to (a) assess system reliability based on analysis at any equipment indenture level within the system; (b) evaluate the effect of equipment storage life, alternative maintenance practices, and packaging on overall system and subsystem reliability; and (c) determine spare part inventories required for support of the system in terms of modularized equipment at any indenture level. Operations Research Incorporated has applied this model to several weapon systems under development to obtain, among other things, a sensitivity analysis of system reliability as it reflects storage time between maintenances of individual equipment items within the system. More importantly, the model has been used to estimate the "goodness" of maintenance on these items. It has verified, for example, that the probability of equipment repair and the probability of induced failure through maintenance can impact heavily on system reliability.

**TP1.4 A Recovery and Reconstitution Model for the Strategic Strike Forces,** Joseph T. Ryan and Robert H. Thornton, *Research Triangle Institute, P.O. Box 12194, Research Triangle Park, North Carolina.*

During the past several years a family of models relating to thermonuclear war has been developed. These models provide a capability for studying Air Force preparedness and effectiveness, with emphasis on the initial exchange. This paper describes a model design which originated from a realization that the value of these models for Air Force planning could be enhanced by adding capabilities for studying reconstitution of surviving forces to estimate timing, strength, and base locations for a "second strike" capability during a protracted war. To incorporate these capabilities into the complement of war games, and multiply their analytic value to the Air Force, the Recovery and Reconstitution Model (R&R Model) was conceived. The model is one-sided, non-stochastic simulation, but capable of simulating the recovery of both sides in series. It is entirely driven by planner inputs. The inputs can either be "war gamed" computer estimates of damage, or can be estimates derived by other means of the postattack status of bombers, tankers, and other resources critical to a strength assessment. This paper consists of a brief description of the major elements of the model design as well as some potential applications of the model to problems other than strategic strike force recovery.

**TP1.5 The Role of Cost Effectiveness in the Preliminary Design of Vertical Lift Military Aircraft,** William F. Tinsley, *Preliminary Design Division, U.S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia.*

Some of the more unique problems associated with preliminary design of vertical lift military aircraft are discussed and a computerized cost-effectiveness program adaptable to such problems is presented. Unique problems arise since design is against a whole series of mission profiles, few of which can be performed with equal effectiveness by the same aircraft. In addition to the varying size and performance characteristics dictated by mission parameters, a number of different conceptual design approaches must also be considered. This results in from several dozen to as many as several hundred design points, each of which is essentially a different aircraft. Since the final result is to be a single optimized design for the series of missions, compromises must be made in the form of performance trade-offs. During the very early stages of design this places considerable importance on cost, cost-effectiveness and sensitivity analysis in narrowing the choices. Empirical data are generally nonexistent at this time and since there may be as many as several hundred analyses to be made, time simply does not permit using a sophisticated or time consuming approach. The author offers some short cuts found useful in cost estimating in these preliminary phases of R&D.

**TP1.6 The Use of Order Statistics in Estimation,** H. LEON HARTER, *Aerospace Research Laboratories, Wright-Patterson AFB, Ohio.*

A survey is given of recent advances, including a number of original contributions by the author, in the use of order statistics to obtain point and interval estimates of the parameters of various statistical populations from complete and from censored samples. In a few cases estimators based on order statistics are the efficient estimators, but more often they are substitute estimators which sacrifice some efficiency in the interest of computational simplicity and/or robustness in the presence of outliers. In life testing, they are often used to obtain estimates of the parameters of the life distribution before all of the items placed on test have failed. Point estimators based on order statistics may be either best linear unbiased estimators, based on all available observations from complete or censored samples or on one or more observations chosen in some optimal manner, or maximum-likelihood estimators, based on censored samples, of a single parameter or of two or more parameters jointly. Interval estimators may be based on percentage points of order statistics or of functions of order statistics, or they may be based on asymptotic variances and covariances of maximum-likelihood estimators. A summary is given of available results, together with a list of references and examples of applications to such problems as estimating the scatter of bullets aimed at a target and the reliability of an electronic device.

**TP2.1 Solution of the 1-Center Problem, the *m*-center Problem and the Location-Allocation Problem,** MYRON R. ROSENTHAL and SPENCER B. SMITH, *Department of Industrial Engineering, Illinois Institute of Technology, Chicago, Illinois.*

An extremely fast method is devised for locating the absolute center of a network using the central path technique (the absolute center being defined as that point on the network which minimizes the maximum distance to any node of the network). An extension using this technique is then used in an iterative manner to solve the absolute *m*-center problem; computational times will be stated in the discussion. Finally, the computational aspects of a combinatorial solution by network methods of the location-allocation problem. Applications of these techniques will also be covered.

**TP2.2 Maximizing Flow Through a Network with Node and Arc Capacities,** RICHARD D. WOLLMER, *The RAND Corporation, 1700 Main Street, Santa Monica, California.*

In many actual network flow situations, nodes as well as arcs have limited capacities. In this paper, an algorithm for maximizing the flow from a source node to a sink node in such a network is presented. This algorithm allows us to treat these situations without introducing artificial arcs and nodes as has been done in the past. In addition, the following generalization of Ford and Fulkerson's max-flow min-cut theorem is presented and proven. Consider two subsets of the nodes, $X$ and $\bar{X}$, whose union is the set of all nodes in the network and such that the source node is a member of $X$ and the sink node a member of $\bar{X}$. Then the nodes in the intersection of $X$ and $\bar{X}$, and the set of all arcs $(i, j)$, such that $i$ is a member of $X-\bar{X}$, and $j$ is a member of $X-\bar{X}$, form a cut set separating the source and the sink. Letting the value of a cut set be the sum of the capacities of all its arcs and nodes, it follows the maximum flow is equal to the minimum value of all cut sets separating the source and sink.

**TP2.3 Contingency Modeling by Oriented Graphs,** Myron A. Wilson, *General Electric Company, Re-Entry Systems Dept., Philadelphia, Pennsylvania.*

Projects are often characterized by uncertainty, not only of the times to complete constituent activities, but also as to whether certain conditional activities will ultimately be undertaken at all. PERT and related critical path techniques are unable to represent contingent network structures, thus their relevance as models is limited by the extent to which the user is able to forecast the activities and events that will actually be realized during a project. A project involving contingencies can be modeled by an oriented graph $(N, R)$ where the arc subset $R$ is not invariant, but is defined for any passage through the network by a Markov process. Associated with each possible arc is a random variable, the arc passage time, and a conditional probability of traversal. Given that a node $j$ has been reached, there exists a probability $p(jk)$ that the task $jk$ will prove necessary and that the arc $jk$ will therefore be traversed. The distribution through the network is obtained by simulation. For selected arc density functions, the distribution is obtainable analytically, by convolution of the densities of series-connected arcs, and by forming the products of the distribution functions of parallel arcs.

**TP2.4 Analysis of Algorithms for the Zero-One Programming Problem,** Ronald L. Gue and Kenneth C. Cain, *Department of Industrial and Systems Engineering, University of Florida, Gainesville, Florida.*

The linear programming problem where the variables are constrained to values of zero or one has been called the zero-one programming problem. Several algorithms have been proposed for the solution of the problem. The advantages and disadvantages of four of the more promising of these algorithms will be discussed together with areas of future research. The authors' computational experience with the four algorithms will be covered. Machine time and storage requirements over a wide range of problems will be given.

**TP2.5 Decomposition Programming, Macro-Micro Structure,** Earl J. Bell, *School of Business Administration, University of Washington, Seattle, Washington.*

A petroleum blending problem was analysed in order to compare the primal and primal-dual decomposition algorithms. In the course of the analysis, a microstructure is discovered which has relevance to the relative performance of the two algorithms and to their absolute performance as compared with a standard primal-

Simplex solution without decomposition. In the literature on mathematical programming, examples abound of special algorithms designed to take advantage of particular matrix structures. In this paper, by macro structure we shall mean a pattern exhibited by a matrix when arranged into sub-matrices, while micro structure will be reserved for the nature of the submatrices themselves. Thus, an identity matrix is a case of micro structure because of the diagonal terms and also because there are only zeros and ones. Similarly, a null vector is an illustration of micro structure. The algorithms which employ the Decomposition Principle illustrate the use of macro-structure, while the transportation algorithms illustrate the use of micro-structure. Our point in this paper will be to show that the efficiency of decomposition algorithms can be improved by considering the micro-structure in more detail. To some extent this already exists if one allows that the subprograms may be of the network or transportation type, or for that matter, even decomposition programs themselves.

**TP2.6 An Algorithm for the Quadratic Assignment Problem,** G. W. GRAVES, *Western Management Science Institute, University of California, Los Angeles, California,* and ANDREW B. WHINSTON, *Purdue University, Lafayette, Indiana.*

The paper presents a new approach to solving a class of combinatorial economic allocation problems. One member of this class is known as the quadratic assignment problem. Besides presenting an algorithm to solve this problem, we will discuss in general terms the techniques for treating combinatorial problems. A novel feature of the paper is the development of the statistical properties of the criterion function. These statistical properties are used in conjunction with a general enumerative procedure to form the main parts of the algorithm. Using the idea of confidence level enumeration an extension of the algorithm is proposed which should allow for the effective treatment of large scale combinatorial problems. Finally we present some computational results in order to illustrate the effectiveness of the general approach.

**TP2.7 A Plant Location Algorithm Related to Direct Search Mixed Integer Programming,** KURT SPIELBERG, *IBM Scientific Center, New York, New York.*

The algorithm deals with the production of a single commodity at a proposed set of $m$ plants and its distribution to a set of $n$ customers. It decides which plants are to be operating and how the demands are to be satisfied. The algorithm is not heuristic (although it could incorporate heuristic elements, if so desired), as is previous work by E. Feldman, E. A. Lehrer and T. L. Ray, and relates to the algorithm of M. A. Efroymson and T. L. Ray as does the mixed-integer algorithm of C. E. Lemke and the author (combining elements related to the integer programming search technique of E. Balas and the partitioning algorithm of J. F. Benders) to the Land and Doig algorithm. Among other things we hope, from our experience with this algorithm, to gain more insight into the possible behavior of a general mixed integer algorithm. Preliminary experience with an experimental plant location program has included the complete solution of 30–40 plant and 35–80 customer problems in one to three minutes on a 360/40 computer of IBM. We are cautiously optimistic about the prospect of solving problems with as many as 100 plants and 100 customers in reasonable time.

**TP2.8 A Nonlinear Programming Approach to Facilities Location Problems,** ROBERT F. LOVE, *University of Wisconsin, Madison, Wisconsin.*

We consider the problem of finding the locations of any finite number of facilities which are optimum with respect to the total cost of transporting known quantities of goods from these facilities to each of any number of destinations. The total cost is assumed to be a linear function of the facility-to-destination distances. Known quantities of goods may also be transported from any one of the facilities to any of the others. In this paper it is proven that the total cost function for this problem is convex, demonstrating that a unique optimal solution exists which may be located by gradient methods. The convexity proof provided here also provides the basis for the formulation of constrained problems of this type which may be solved by nonlinear programming techniques.

**TP2.9 The Tank Assignment Problem II,** LAWRENCE BRISKIN, *The Carborundum Company, Niagara Falls, New York.*

The Tank Assignment Problem considers the problem of assignment of tanks to products at tanker terminals in a multiproduct system with tanks of various sizes. In a previous paper (29th National Meeting, ORSA), this combination problem was formulated and solved as an Integer Linear Programming Problem. Computational difficulties, wherein one Integer Linear Programming algorithm yielded an incorrect solution and another required over 8000 iterations to achieve the correct results, all for a 4 product, 11 tanks of 3 kinds problem, indicated the need for an improved solution procedure. In this paper the problem is formulated with a minimax objective function and solved by the method of "convergent exhaustive search." Computational results are given for problems as large as 25 products, 117 tanks of 25 kinds.

**TP2.10 Solution Characteristics of Zero-Sum Games by an Approximation Technique,** JAMES C. HECKMAN, *Hughes Aircraft Company, Space Systems Division, El Segundo, California.*

This study summarizes the results from a computer program written for the G.E. 235 time-sharing system. Purpose of this report is to emphasize the accuracy, simplicity, and solution characteristics of "The Method of Fictitious Play," and compare the results with other game solving techniques, such as linear programming. Included in the report are analytical and graphical results showing: (1) computer time required to solve the $N \times M$ game; (2) solution convergence characteristics; both the convergence of the game "value" and that of the "optimal strategy" allotment are considered; (3) suggested criteria for ending the game; (4) effects of more than one basic solution on the approximation. It is shown that the method is surprisingly effective for games with pure strategy solutions, making it unnecessary for preliminary saddle point checks. The method gives accurate mixed strategy solutions for relatively small computer times.

**TP3.1 *A Dynamic Modeling Approach to Bank Asset Management,** A. J. PHIPPS, JR., *Bonner & Moore Associates, Inc., 500 Jefferson Building, Houston, Texas 77002.*

As banking activities become more diverse and the business environment evolves faster and faster, the complexity of general management in banking is intensified.

This paper discusses the usefulness of applying dynamic simulation as an aid in general bank management decision making. The Asset Management model used to illustrate dynamic simulation contains three basic blocks: An external environmental conditions submodel, a bank internal system submodel, and a submodel for calculating operating results. The environment submodel outputs local economic conditions, national economic conditions, and governmental regulation under stochastic control. The internal system submodel considers information gathering, forecasting, and decision making at tactical and policy levels. The operating results submodel calculates financial statistics resulting from the interaction of the decision making and environmental activities. These statistics serve to measure the effectiveness of a particular strategy, or decision system, in a relatively unpredictable environment. The total model is used as a management laboratory for evaluating limited decisions such as whether or not to sell new capital stock or for evaluating new decision rules such as how to react to interest rate changes, or for evaluating improved information networks to speed up or improve accuracy of decisions. The model incorporates the principles of Industrial Dynamics and is programmed in the Dynamo language developed at MIT.

TP3.2 *** Environmental Modeling And Product Conceptualization,** ROBERT D. DAHLE, *Xerox Corporation, P.O. Box 1540, Rochester, New York.*

Simulation of the micro-environment for a product has been used to aid in the definition, design, and marketing of various product concepts. The basic procedure consists of three steps: (1) A detailed microenvironment model is constructed, utilizing statistical and observational data concerning the environment and its operation; (2) Various product concepts are introduced into this environment through simulation and are evaluated as to their relative effectiveness in mitigating the physical and economic problems presented by the environment; and (3) Product concepts which meet the test of physical and economic feasibility are then evaluated against financial criteria to determine their soundness relative to corporate objectives. When the product concept is translated into a salable product, the simulation model is adapted for use by sales personnel in developing their sales presentation. Data concerning the present operation of a potential customer can be input into the model and a comparison made between the customer's present and the salesman's proposed organization. In this way, the customer can obtain an estimate of the applicability of the equipment without disruption of his operation. The paper will cite a specific application in which environmental modeling was utilized as a means of product conceptualization.

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TP3.3 *** Regulation in the Finance Industry: New Frontier for Operations Research,** JOHN D. HOGAN, *The Northwestern Mutual Life Insurance Company, 720 East Wisconsin Avenue, Milwaukee 2, Wisconsin.*

Regulatory authorities have become so important in American political processes that they are sometimes considered a fourth branch of government. It is argued in this paper that the contribution of these authorities to the improvement of the operations they regulate, especially in finance, could be considerably enhanced if operations research techniques were more widely used to set control limits (thereby anticipating some of the failures and avoiding the delay of action until the public has been visibly ill-used to halt a defunct operation or, hopefully, being able to save a failing operation by requiring remedial action); to investigate the interplay among variables in the operations regulated (thus being able to give appropriate counsel and make bona fide representations to firms about their operations); and, to trace the paths of operating statement and balance sheet variables over time (hence, learning more about the structure of growth in the operations regulated and improving the counsel that can be made available to new firms and those considering entry). The price of failure to develop operations research-type analytical tools—especially if firms in the regulated industries develop such tools themselves and use them defensively against the regulators—will be loss of prestige by regulation authorities and, if conspicuous failures of regulation continue, an increasingly hostile judiciary responding to public wrath. The Permian Basin case, in which the Federal Power Commission recently won a consent decree from natural gas producers on the strength of exhibits based on a supply-price model, marked the beginning of the end for the prevailing legalistic standards of regulatory evidence. The paper presents models illustrating the use of operations research tools for the three purposes suggested—setting control limits, investigating interplay among variables, and tracing paths of variables over time.

### TP3.4 *Empirical Tests Of The Compatibility Of Selected Equity Share Price Equations With A Descriptive Dividend Model, JAMES L. BICKSLER, *Stanford Research Institute, Menlo Park, California.*

The subject of finance has undergone a tremendous transition in the last decade. No longer is the study of finance an examination of rules of thumb and vague guidelines for decision making. Instead a normative theory of finance has developed whereby decisions concerning sources and uses of funds are made in the context of maximizing the price of a firm's equity shares. However, "a fundamental problem still exists—the absence of a model of financial behavior which deals effectively with problems in the normative literature of business finance." (Shapiro & White, "Patterns of Business Financing: Some Comments," *J. Finance*, Dec., 1965). This study attempts to relate the dividend behavior as explained by a descriptive dividend model and determines if this is the pattern suggested by corporate equity share price equations to maximize the price of the equity shares. First, a theoretical exposition states how the amount of dividends should vary with the relative importance of dividends and retained earnings as determinants of the price of equity shares. Secondly, cross section regression tests are made on fourteen different industries and an all category (the fourteen industries combined) for each of the six years from 1959 through 1964 for selected descriptive stock price models and a descriptive dividend model. Three different statistical tests are then conducted to determine if the assumption of the maximization of equity share prices affords valuable insights into corporate dividend practice. The statistical tests are: (1) Spearman rank correlation; (2) Simple correlation; (3) Chi-square. The paper concludes with: (1) A summary of the findings and limitations of the employed methodology; (2) Suggestions for more ingenious empirical tests; (3) Implications for current research in (a) finance theory (b) actual financial decision making in the firm.

### TP4.1 Optimum Transportation Network by Mechanical Analogy,

Claude Riveline, *Paris School of Mines, 60, Boulevard Saint-Michel, Paris (6°), France.*

The original aim of the study was to find the optimum network of galeries connecting, in an underground horizontal plane, one or several pit-bottoms to a number (15 to 30) of loading-points distributed in that plane. The relevant parameters are: the costs of driving and maintaining the galeries, the costs of transportation, the cost of the time lost by manpower in transportation, the dates at which those expenses occur, and the uncertainties about the future. The problem of the shortest network is completely solved by Kruskal and Sollin's algorithms, and Steiner's theorem, but it only takes into account the cost of driving. The overall optimum can be computed, but that requires, even for a limited number of points, extremely long calculations. But it has been proved that the optimal solution can be found by materializing in a plane the mechanical equilibrium of threads, each thread being submitted to a tension proportional to the marginal cost of the corresponding section of galery. This mechanical analogy has been recently applied in French coal mines, and it has saved about 15% of the total expense expected. The method can be applied to other transportation networks.

### TP4.2 A Method for Determining the Optimal Composition of an Aircraft Fleet,

Richard F. Serfozo, *The Boeing Company, Box 3991, Seattle, Washington.*

A linear programming model for determining the optimal composition of an aircraft fleet is presented. The fleet must be able to provide a designated level of productivity on various tasks over a period of time. It may consist of new, existing or remodeled aircraft types which have certain, respective productivities on the different tasks. The cost of the fleet is the operations and maintenance (O&M) cost, plus the cost of procuring additional aircraft, plus the research, design, test and evaluation (RDT&E) cost associated with the new aircraft types in the fleet. The model determines the quantities of each aircraft type, used for each task, in each time period, that provides the fleet productivity at least cost.

### TP4.3 A Global Optimization Problem in Bus Scheduling—Satisfaction of Passenger Demand with Minimum Number of Coaches and Crews Subject to Constraints of Union Contracts on Crew's Working Conditions,

Yoshiro Kuratani, *Case Institute of Technology, Cleveland, Ohio,* Mitsuhiko Murate, *Nagoya Railways, Nagoya, Japan,* and Toshio Ochi, *Hideo Nagae, Nitachi, Ltd., Tokyo, Japan.*

Assignment of crews to coaches scheduled on a network of buslines has long been a source of headache for a majority of large-scale bus companies in Japan, particularly when a substantial revision of an overall bus schedule became necessary to meet changing passenger demand for bus services. This problem has recently become a serious concern of the management of a bus company due to the acute shortage of coach crews coupled with the pressing demand for better working conditions by its labor union. As a matter of fact this assignment problem has become so difficult to solve that a number of days, often more than a week, had to be expended by a group of scheduling specialists trained in the company for many years to arrive at a feasible trial-error solution for a problem of a moderate size. The research reported in this paper is a culmination of the joint efforts of the participants in this research project who attempted to solve this problem by viewing it embedded in an overall optimization problem in bus scheduling. The branching and bound method, heuristic approach, and simulation methods were employed in combination to attack various components of the problem, first separately and then in an integral fashion to arrive at a set of overall solutions by an iterative procedure. The assignment problem of the size that required approximately 50 man-days was solved in 1.5 hours on HITAC 5020.

**TP4.4 The Delivery Problem,** ROBERT L. HAYES, *Graduate School of Industrial Administration, Carnegie Institute of Technology, Pittsburgh, Pennsylvania.*

In the delivery problem we are given a fleet of delivery vehicles of fixed capacity and a homogeneous commodity to be distributed in known amounts to various customers. We desire to minimize total distance traveled by the vehicles subject to the constraints: (1) Each vehicle must start and finish its route at one central warehouse, and (2) The demand of each customer must be exactly met. This paper examines various approaches, both algorithmic (i.e., guaranteeing an optimum) and heuristic, which have been proposed for solving the delivery problem. The different methods are compared on the basis of computational requirements and quality of solution.

**TP4.5 On the Solution of Truck Dispatching Problems by Combinatorial Programming,** JOHN F. PIERCE, *Massachusetts Institute of Technology, Cambridge, Massachusetts.*

One of the generalizations of the traveling salesman problem is that termed the Truck Dispatching Problem wherein deliveries $q_1, q_2, \cdots, q_n$ are to be made from a central depot to $N$ geographically dispersed destinations $D_1, D_2, \cdots, D_n$. Since for all carriers the capacity of the carrier $C < \Sigma_i q_i$ it is not possible to serve all points on a single trip which links all destinations. For some destinations there may be an earliest delivery time and/or a delivery deadline which restricts the acceptable delivery time at the destination. The problem is thus to determine the carriers to be employed together with the routing of stops for each so as to minimize total variable delivery costs. For solving problems of this type, procedures based on the methods of combinatorial programming are discussed and computational experience on an IBM 7094 is summarized. All procedures are reliable in the respect that when carried to completion they guarantee the discovery of an optimal solution.

**TP4.6 Detection of Acceleration in Car-Following,** WILLIAM J. WHITTY and LUCIEN DUCKSTEIN, *Systems Engineering Department, The University of Arizona, Tucson, Arizona.*

An important component of the reaction time of a vehicle driver to a change in driving conditions is the detection time. In this study, a car-following situation was considered and an experiment was designed to measure the time which a following driver takes to detect a change in velocity of the lead car. The instrumentation is described and experimental data are presented. The results of an analysis of variance and of a regression analysis are then given. The drivers studied exhibit increasing detection time for decreasing acceleration. Regression analysis indicates that, for the range of values included in the experiment, detection time is a linear function of acceleration. On the basis of the results obtained to date, an outline for further research is given.

**TP4.7 The Oversaturated Signalized Intersection: Some Interarrival Statistics and a Probability Model,** Clinton J. Ancker, Jr. and Antranig V. Gafarian, *System Development Corporation, 2500 Colorado Avenue, Santa Monica, California.*

An oversaturated signalized intersection, with no turning permitted, is examined. Data on the time between arrivals of successive vehicles at the intersection has been collected and analyzed statistically. It is shown that Erlang density functions fit the data satisfactorily and that all vehicles from the third on may be considered as members of the same population with different means. The mean arrival times decrease from front to rear with all from the eighth on being the same. In addition, it is demonstrated that all interarrival times are independent. Experimental techniques and statistical methods are fully described. A renewal model to fit these data is developed.

**TP4.8 Dynamic Control of Traffic Input into an Urban Complex,** William D. Rabin and Lucien Duckstein, *Systems Engineering Department, The University of Arizona, Tucson, Arizona.*

A general model is presented for the problem of studying, then controlling traffic input into a large urban system with multiple activities. The central business area of New York City, which is a gigantic center engaged in a whole spectrum of industrial and commercial activities, is taken as a case study. This area has several fairly well-definable districts, each of which engages in a specific type of economic activity. The destination of most of the incoming traffic can be determined before it enters the city. Thus, for a given time of the year, the traffic flow for a particular district can be predicted along each inbound and outbound route. Given these predicted flow rates and an indication of the present conditions in each district, an algorithm is proposed to control a given inbound flow rate—namely, the one through the Lincoln Tunnel—in order to increase the total rate of supply of men and materials into the central business area. The efficiency of a large urban system may thus be increased by controlling one of its important input terminals.

**TP4.9 An Urban Transit Laboratory,** Ernest B. Cohen, Theodore Gordon, and Solomon Moldoff, *General Electric Company, P.O. Box 8555, Philadelphia, Pennsylvania.*

This *trio* of papers presents a plan for long range comprehensive experiments in urban transportation. The plan is based on gradual redevelopment of an existing area with minimum removal or new construction of buildings. A public transportation system would serve as a test bed for vehicle and guideway engineering experiments and for new operating concepts. The most crucial result of the experiments will be clarification of social need by analyzing public reaction. The experimental program is discussed in terms of a specific implementation in suburban Philadelphia.

### *Land Use*

The land use experiment attempts to closely integrate a transit line into a community structure. The stations are closely spaced and connected to the residences by pedestrian walks. This pattern will gradually evolve by closing the streets to through traffic. Traffic generating centers (stores, schools, etc.) will be encouraged to locate in close proximity to the transit line. Additional services, such as package delivery, would be provided at the major stations. Besides being convenient for local trips, the line will connect with two major suburban shopping centers, and with high-speed rail lines to central Philadelphia. As an experimental control, half the route would merely run down the median strip of an existing major street.

### *Engineering*

The same right-of-way is expected to serve as test bed for several generations of vehicles and operating concepts. The first generation vehicle will be compatible with standard railroad trackage. The emphasis will be on field testing a vehicle which can be mass produced for a wide range of urban transit applications. Attention to details will result in major improvements in comfort, flexibility of operation, and maintainence. Right of way improvements will emphasize quiet operation, use of naturalized plantings, and safety design. Operational changes will consider handling of packages and the interaction of operator and passengers. Later experiments will operationally test new propulsion, guidance, and suspension techniques. Unmanned vehicles and continuously moving systems will be operated in the last round of engineering experiments.

### *Social Considerations*

The experimental area includes two working class districts, mostly middle class neighborhoods, and an upper middle class section. Because the area consists of discrete neighborhoods, each with an individual character and economy, it is particularly suited for observing the social effects of service variations. The innovations will include special provision for both aged and immature patrons. Other direct services will include provisions for parcels and shopping carts. Indirect services will include recreation facilities along the right of way, stands for newspapers and sundries, and neighborhood police protection. The effect of planned relocation of facilities, such as schools, will be measured. The voluntary migration of traffic generators, including stores and offices, must also be observed over an extended time period. Additional experiments can be conducted in employee motivation and intergovernment/private agency coordination problems.

## TP5.1 *An Heuristic Approach to Combinatorial Decision Problems,

A. J. Rowe, *University of Southern California, Los Angeles, California.*

The solution of large-scale combinatorial problems is generally difficult in view of the inability to enumerate all possible combinations. Specific problems can be solved by linear programming, dynamic programming, etc. However, the generalized combinatorial problem has not yielded to solution. The branch and bounds approach reduces the number of possible solutions to be considered. An heuristic approach is proposed which "transforms" the combinatorial problem into a search problem utilizing suitable classification of the elements and decision criteria or objective function subject to specified constraints. Application of this approach to a number of problems is given.

### TP5.2 * **Comparative Analysis of Real Time Simulation,** JOHN COLLEY, *Research Triangle Institute, Durham, North Carolina.*

Past efforts in a number of companies have led to significant advances in attempts to implement real time systems for scheduling and controlling production in large shops. Such efforts have been underway for some years in a number of industrial companies. General Electric contributions have ranged from developing the first general purpose factory simulator (later widely distributed through IBM) to specific applications in scheduling both large and small shops. Western Electric supported, along with GE and others, the important work of the Cornell University Production Control Research Committee in the late 1950's. After several pilot installations in small shops, Western Electric personnel designed, for the company's Kansas City works, as near to a real-time production system as the computer art would allow. Hughes Aircraft personnel were engaged in simulation studies for some years and in 1964, successfully implemented a daily simulation/scheduler in a medium scale machine shop. The paper critically evaluates the work to date in this area and discusses developments most likely to evolve in this field in the near and long-run future.

### TP5.3 * **Design of Computerized Workload Forecast and Shop Loading System,** D. G. MALCOLM, *Management Technology Inc., Los Angeles, California.*

LTV Aeronautics Division has designed and implemented a computerized workload forecast and shop loading system. This paper describes the nature of the design process as applied to a complex manufacturing problem and illustrates the solution by an actual application. The system considers total open workload, open work behind schedule, open work on schedule, and work to be dispatched. Computer reports are produced to the work center level (foreman) weekly, which reflect a simulated position to schedule, manhours required to economically work off behind-schedule work, and recommendations for leveling future open and to-be-dispatched workloads.

### TP5.4 * **Algorithms for Optimal Production Scheduling and Employment Smoothing,** STEVEN A. LIPPMAN, ALAN J. ROLFE, HARVEY M. WAGNER and JOHN S. C. YUAN, *Stanford University, Palo Alto, California.*

The problem of determining an optimal employment schedule is classic to operations research literature. Even in a deterministic environment it is not trivial to minimize the total cost of production, inventory, and work force fluctuations. The optimal employment scheduling model in this paper is a particular specialization of a more general situation we studied elsewhere: Here we postulate that all production costs are described by linear functions. The specialized model in this paper can be classified as a highly structured linear programming problem. We will seek here a minimum cost production plan over a finite number of time periods.

There is a known demand requirement (stated in production hours) to be met in each period from current and previous hours of production (stored as inventory). A production plan consists of scheduled amounts of hours, some of which are costed at regular time wage rates, the remainder costed at overtime rates. Expansion or contraction of the work force (stated in production hours) is charged against the period to period variations in regular time employment. The fluctuations in overtime production do not incur such hiring and firing costs. The amount of overtime used, however, is constrained not to exceed a specified fraction of regular time utilized in any period. Therefore, our model crucially differs from that in the classic operations research literature in that we have included the restricted option of overtime as a substitute for increasing the work force. The paper provides complete algorithms for the cases of increasing demand requirements and decreasing demand requirements. Further, we provide an analysis of the solution sensitivity to the horizon length.

**TP5.5 * A Loading Problem in Process Type Production,** SALAH E. ELMAGHRABY, *Yale University, New Haven, Connecticut.*

In recent years attention has been given to a class of scheduling and loading problems in which the mathematical formulation leads to a combinatorial enumeration of alternatives. The programming model thus developed [normally a linear program (LP)] has integer variables, usually of the 0, 1 type. The number of these variables is large since one variable is defined for each alternative and, for any real life problem, the combinatorial count of these alternatives is very large. Our formulation shares with others the combinatorial nature of activity generation and is also formulated as an LP with 0, 1 type variables Our formulation also shares with the others certain limitations as well as serious objections to the manner in which some costs have been treated. We apply the decomposition principle to the LP and generate a nonlinear program in integer variables as a sub-problem to be resolved at each iteration. This sub-problem is solved under a special condition which we believe to be the most commonly realized condition. The paper presents a small numerical example that illustrates the setting up of the model for computing purposes.

**TP5.6 * An Ordering Policy When Delivery Can Be Expedited,** S. G. ALLEN and D. A. D'ESOPO, *Stanford Research Institute, Menlo Park, California.*

The ordering policy considered for a stock item is of the familiar $(s, S)$ type, except that an additional quantity $x$ $(<s)$, called an expediting level, may be specified. When stock on hand is reduced to $x$, then an outstanding order will be expedited and received in a time period $L_E$, called the expedited leadtime, which is less than the normal procurement leadtime $L$. Even though $L$ and $L_E$ are assumed constant, the effective leadtime becomes a random variable distributed over the interval $(L_E, L)$. For a general class of demand distributions, expressions are given for the expected inventory, shortages, number of orders, number of expedited orders, and number of expedited units ordered, all per unit of time. Conditions for choosing $(x, s, S)$ to minimize the sum of the costs associated with these expectations are given. Numerical examples of $(x, s, S)$ satisfying these conditions approximately are worked out for comparison with the corresponding (optimal) choices of $(s, S)$ policies with no expediting levels assumed.

**FA1.1 * Methods for Classifying Terrain and Introducing Terrain Effects into Analytical Models of Low Altitude Defense System Effectiveness,** RICHARD H. ROSE and LARRY T. ROTH, *Caywood-Schiller, Associates, Chicago, Illinois.*

Recent interest in low altitude operations of military aircraft, and defense against such operations, has focused attention on characteristics of terrain, and the effects of terrain, on the performance of low altitude air defense systems. This paper presents methods for determining terrain roughness, classifying terrain according to roughness, and considering the effects of terrain on the performance of defense systems based on data obtained from topographic maps. The average value, standard deviation, and correlation coefficient of the average terrain altitudes from sub areas is calculated. It has been found that the product of the standard deviation and the correlation coefficient is a useful measure of terrain roughness and can be employed to classify various terrains. Analytical models of air defense system performance often incorporate terrain effects by use of mask angle. The inadequacies of this approach to representating terrain are shown and an improved method of representing terrain masking effects is presented.

**FA1.2 *Fighter Aircraft Evaluation for Aerial Combat,** DON W. MOODY, *The Boeing Company, Box 3991, Seattle, Washington.*

The primary guideline for future generation air superiority fighter aircraft is to be superior in performance to any anticipated threat. Performance for a fighter system includes both the aircraft and the associated missile system. Although very refined air-to-air missile delivery systems have been developed, political limitations have prevented the use of their full potential and in fact many of the air battles in Vietnam have been old fashioned high load factor aerial dogfights. To determine the aircraft maneuverability required for an aircraft, a fighter aircraft dogfight simulation model is employed. This model evaluates the relative tradeoff of speed ($V$), load factor ($G$), and time. Inputs for the model are based on data obtained from computer models of aircraft energy-maneuverability. The output of the model is a plot of aircraft trajectories and conversion conditions.

**FA1.3 *System Analysis of a Low Altitude Air Defense Weapon,** LARRY B. JAMES, *Douglas Aircraft Co., 5301 Bolsa Avenue, Huntington Beach, California.*

This paper addresses requirements for a new type SAM for operating as an area-attrition or point defense weapon in tactical warfare. The approach consists of defining system requirements, a synthesis of an optimal system, and cost-effectiveness comparisons of the system with other units. Scenarios and orders-of-battle are prepared for three geographical areas of probable envolvement. Using these scenarios, three war games are reported in which a red team/blue team approach was used to develop engagement statistics to describe firing situations that would be encountered by the SAM units. Over 1000 engagements between SAM units and aircraft raids were analyzed to produce statistics relating to target acquisition, target motion and target ground path geometry relative to the firing site. The effects of terrain mask were accounted for. Using the statistics, an optimal SAM system was synthesized, considering constraints to satisfy air and ground mobility and U. S. Army manning and organizational structure. The system is structured within a hypothetical Army organization to allow complete cost analysis. Effectiveness models which utilize war game statistics are used to compare it with competitive systems. Cost effectiveness calculations are presented to indicate desirability of the concept.

**FA1.4 A Simple Operational Model for Evaluating Increased Performance in a Tactical System,** GENTRY LEE and W. L. PADIA, *Systems Analysis, The Martin Company, Denver, Colorado.*

This paper demonstrates how a simple operational model, using a small digital computer, can be used for military evaluation of suggested improvements in a tactical system. A specific problem is posed. Consider a field missile being used to protect targets against airplanes carrying rockets or small missiles. Several improvements for the field missile are being considered and each is accompanied by an estimated cost. By simulating a simplified war-game in which the field missile is to be used against known enemies, is it possible to estimate rapidly which of the possible improvements provides the most return (in terms of increased probability of a favorable outcome of the basic war-game) for the least cost? A computer model is designed that not only provides rapid answers to this question for a simplified war-game, but also permits easy extension to the case of a more complex gaming analysis. A hypothetical example is calculated using the model and the role of the model in the resultant military decision-making is discussed in terms of the example.

**FA1.5 A Dynamic Detection and Sequential Allocation Problem,** JOHN R. HOLDSWORTH, *The Bissett-Berman Corp., 2941 Nebraska Ave., Santa Monica, California.*

The purpose of this paper is to present a dynamic programming formulation and solution of a class of tactical problems of which the following is representative. A defensive site is equipped with $I$ interceptors, each having an acquisition and kill probability $P_k$ when targeting an enemy warhead. The defense is attacked by a re-entry cloud of $W$ warheads and $D$ decoys which arrive sequentially at a certain decision altitude. When an object arrives at this altitude, the defense makes a binary measurement of the object which is characterized by two numbers, $P_{ww}$, $P_{dw}$ where $P_{ww}$ is the probability that a measurement on a warhead exceeds a threshold and $P_{dw}$ is the probability that a measurement made on a decoy exceeds the threshold. Given the measurement sequence observed thus far, the available number of interceptors, and possibly the apriori probabilities of the arrival sequences of the reentry objects, the defense must allocate a certain number of interceptors, possibly zero, to the object so that the expected number of surviving warheads is minimized. Certain generalizations are discussed such as the inclusion of the measurement threshold setting as part of the optimization problem. Various analytical and numerical results are obtained and comparisons made with the case where all objects in a cloud can be simultaneously observed. Also some attention is given to how the offense should design decoys subject to a weight constraint in order to maximize this minimum expected number of surviving re-entry warheads.

### FA1.6 A Model Using Approximate Silhouettes to Compute the Probability of a Single Shot Kill, LAWRENCE J. GRANT, *Lockheed Missiles and Space Company, Sunnyvale, California.*

When it is necessary to compute probabilities of target coverage, usually the exposed area of the target is approximated by either a circle or an ellipse and the circular normal probability density function is integrated over that region. Certain classes of problems, such as finding the probability of killing an aircraft with ground artillery, require more precise approximations of this probability. This paper discusses a computational technique in which the shape of the target is retained by approximating its silhouette with a series of adjacent convex polygons. Assuming that the coordinates of the shot are jointly distributed according to the bivariate normal probability function, an established technique is employed that allows one to integrate this function over each individual polygon. The "total" probability of target coverage, due to the mutually exclusive property of the single shot, is the sum of the probabilities that the point is contained within each polygon. In addition to the aforementioned application, cases may arise in which some sections of the target are more vulnerable than others. Where reasonable estimates of the conditional probabilities of kill given hit in a particular section exist, this technique will yield the probability of killing the target. Results from this method and those obtained from circular or elliptical approximations will be compared.

### FA2.1 *Finite-State Processes and Dynamic Programming, R. M. KARP and M. HELD, *IBM Watson Research Center, Yorktown Heights, New York.*

The simple idea underlying dynamic programming is the representation of certain optimization problems by processes which evolve from state to state in response to decisions. The present paper explores the logical requirements on such representations. The set of possible representations of any given discrete, deterministic optimization problem is characterized, and this characterization is shown to permit the systematic (and nearly automatic) derivation of dynamic programming algorithms. Several typical applications will be discussed.

### FA2.2 *Geometric Programming, ELMOR PETERSON, *University of Michigan, Ann Arbor, Michigan.*

Geometric programming treats two different, but related, classes of nonlinear programs. The programs in one class arise in engineering design and are called primal programs. Those in the other class arise in chemical equilibrium and are called dual programs. There is a one-to-one correspondence between the two classes, and a duality theory based on classical inequalities relates each primal program to its corresponding dual program. This duality provides information about both programs that is not available from either one alone.

### FA2.3 *Methodology for the Precise Handling and Manipulation of Qualitative Information, R. S. LEDLEY and JAMES B. WILSON, *National Biomedical Research Foundation, Silver Spring, Maryland.*

This paper reports a methodology for precisely handling qualitative information that involves relations described in terms of word statements, with the purpose of developing a result which suggests a course of action. For a particular class of problems, there is a set of overall basic qualitative guiding relations. We shall describe a methodology for applying any such quantitative rules in any particular situation so that a course of action can be developed automatically by a computer. A set of "syntax definitions" are written to embody the ideas, concepts and relations basic to the particular class of problems considered. For any particular situation, a "situation string" is written in ordinary words that symbolizes the particular circumstances to be analyzed. The computer program correlates the situation string with the syntax to derive an "action string," or prescription for course of action. The features of the methodology are, first, that it enables computer handling of qualitative relations to develop action decisions; second, that the user is not limited to any particular words of a given language but can use plain text or any type of user-specified language, making the computer "language independent" and the problem-language "computer independent"; and third, the methodology incorporates simple aids to writing the syntax to enable the incorporation of logic nets or flow diagrams.

**FA2.4 *Progress in Integer Programming,** MICHEL BALINSKI, *City University of New York, New York, New York.*

This talk will review some of the recent salient work in the methods, the uses and the computational success of integer programming.

**FA3.1 *Industry's Changing Man Specifications for OR Positions,** HERBERT HALBRECHT, *Halbrecht Associates, Inc., Washington, D.C.*

The first industry recruiters to interview graduates of OR educational programs operated without the benefit of carefully drawn position guides and man specifications. They appeared on campus looking for "mathematicians", "statisticians" "experts in linear programming", etc. They made two dubious assumptions (1) that universities granting degrees in OR had a clear concept of the relevant body of knowledge and (2) that, in acquiring said knowledge, the professionals in question also acquired a perspective and work habits which were compatible with a business environment. Feedback from firms specializing in recruiting people with OR skills indicates that industry now questions both assumptions. Today, businessmen seeking candidates for positions as OR-Managers and OR-Specialists have definite man specifications in mind. The advanced degree in OR is no longer the magic key which opens all doors. Candidates are being closely queried about their academic qualifications, business experience and personal goals. Many firms are shying away from the candidates seeking an academic enclave within a business environment. It is important for educators to be aware of the shifts which have occurred in man specifications over the past decade. It is imperative that they design educational programs which yield better qualified candidates for the challenging careers now opening up in the OR profession.

**FA3.2 *OR Courses for OR Clients,** DONALD S. HOLMES, *Graduate Studies, Union College, Schenectady, New York.*

It is an established fact that the response of many businesses to high quality OR work has been less than ideal. One reason is that managers are reluctant to act on results which they do not comprehend. An OR component in General Electric's Large Steam Turbine-Generator Department turned to an educational program as one vehicle for involving operating people in the construction of models of business systems and in the utilization of existing OR models. Various elementary in-house courses in applied statistics and elementary mathematics were offered. Instructors came from the OR group. Courses in OR techniques were added as the client's interest and understanding grew. Operating people were also encouraged to pursue advanced work in Union College's Industrial Administration program. The fact that the College employed OR men from GE departments as adjunct professors made it possible to teach from case material generated in the Schenectady area. After several years of this type of an educational partnership, the LST-G Department now has a core of operating people thoroughly exposed to OR methods. These men are disposed to generate new OR projects, to collaborate in the construction of models and, most important of all, to act on the basis of OR findings. This experience suggests that, instead of merely expanding collegiate OR courses which make professional OR men still more professional, more could be done for OR clients. To this end, a limited partnership between OR components and colleges adjacent to their plants deserves consideration.

### FA3.3 *Quantitative Studies in a Liberal Arts College, ROBERT R. SINGLETON, *College of Quantitative Studies, Wesleyan University, Middletown, Connecticut.*

A small college faces difficult problems in educating undergraduate students for a world in which Operations Research and related kinds of quantitative analysis have become important elements. Wesleyan University has taken this challenge as an opportunity for a departure in educational principles and method. Students who may eventually do quantitative analysis, and also those who may need only to comprehend its value and use its results, acquire an appropriate knowledge of general theory and some understanding of the relation of theory and theoretical results to real problems. Some specific techniques are taught, but only incidentally. Comprehensive training in technique is not a goal. A significant part of a student's learning is through independent, self-monitored study, and through working on real problems under faculty guidance. In the course of such project work, the student finds he must learn the necessary theory. Through his need to construct models and reinterpret his results meaningfully, he becomes aware of the problems of validity.

### FA3.4 *Effecting a Blend Between OR and Information System Design Work, ERICOLE ROSA, *Corporate Information Systems Education Department, International Business Machines Corporation, Armonk, New York.*

For various reasons, close working relationships between designers of information systems and operation researchers are the exception rather than the rule. The extension of computer-based systems into areas of management planning and control will necessitate much closer integration between these professional groups. Unfortunately, educational programs often do not reflect this need. The usual curriculum isolates, rather than integrates, these fields. A report of IBM's current educational efforts to effect a blend between systems competence and OR competence will be given. Concepts and approaches derived from experiments at their Systems Research Institute are currently being formed into in-house courses tailored to the needs of operating divisions preparing for third generation information systems.

**FA3.5 *Operations Research Under Federal Auspices,** JACK R. BORSTING, *Naval Postgraduate School, Monterey, California.*

A short history of federal educational programs in operations research is given. Operations research requirements and current inventory for the military services are then summarized. Current federally sponsored operations research and system analysis educational programs are outlined. Attention will also be given to the effect on OR educational programs of the recent presidential directive extending DOD planning, programming and budgeting techniques to all cabinet departments.

**FA4.1 *What Do You Mean—Product Design?,** KENNETH A. LONGMAN, *Young & Rubicam, Inc., 285 Madison Ave., New York, New York.*

There are many problems in moving new products from ideas to the market place. The corporation has divided these problems in its organization to R&D, Industrial Design, Marketing, Production, and Finance. It has hampered creativity in its product design by its work procedures. This paper takes the position that by redefining what a product is and by changes in procedural requirements, a number of problems will disappear. A working definition of a product is presented and the importance of that definition to organization and procedure is explored.

**FA4.2 *Modern Automated Shipyard Production Management and Control,** ERNST G. FRANKEL, *Litton Industries, Inc., FDLS Project Assoc. Dir. Technical, 9920 West Jefferson Blvd., Culver City, California.*

In this paper an attempt is made to present an evaluation of the potential of change in the production of ships by automated and continuous fabrication processes with integrated process control and management. Many recent developments in steel fabrication processes have induced major changes in hull construction of ships. In this area, steel plating is cut prepared and bent by automated processes. Stiffeners and shapes are fed to a pre-assembly stage where stiffened panels are then erected which form the building blocks for the ship. Material transfer methods now permit a much more integrated flow and larger modularization, including extensive outfitting of pre-assembled sections which form major blocks of the ship. By such methods, labor intensive outfitting can be spread over a much larger area and larger preassembled outfitting systems can be introduced into these modules at an early stage in ship construction. To permit such an approach, very extensive planning and coordinated management and control of material flow, fabrication processes, manpower allocation, resource allocation, and inspection has to be accomplished: This requires extensive use of sophisticated management information systems, operations analysis techniques, and computer applications. It also forces a complete review of conventional shipyard layout concepts and the requirements of production and material control. This discussion is designed to indicate what tools are available and discuss experiments made to date. It has recently been found that although many modern techniques and processes have been adopted by the ship building industry, no attempt has been made to integrate these various modern tools. In fact, it will be noted that shipyards around the world have taken various approaches in which a limited number of modern techniques and processes are utilized to the exclusion of others. An attempt is made in this paper to indicate how a shipyard might ideally adopt a whole range of modern techniques and processes and integrate these into a well balanced automated high intensity industrial production facility.

**FA4.3 *Schedule Algebra: A Progress Report,** BERNARD GIFFLER, *New York University and C-E-I-R, Inc., Bronx, New York.*

The paper describes a methodology for planning and scheduling called *schedule algebra.* This is both a matrix ring over a field (it differs from conventional matrix algebra in its definition of plus and times and in its characterization of an admissible element as a matrix of sets) and the basis of a mathematical theory of planning and scheduling. The paper describes the algebra, its applications to date, and its possible future. The position is taken that the continuing trend toward product diversification and rapid technological obsolescence is making it necessary to plan and schedule production more carefully than in the past and that this trend is likely to increase the use of schedule algebra or similarly oriented scheduling methodologies.

**FA4.4 A Bayesian Approach to Minimizing Production Testing Requirements,** LAWRENCE HARRIS, *New York University, Washington Square, New York, New York.*

This paper will discuss a behaviouralistic-Bayesian approach to minimizing production testing requirements. Concepts will be described that assist a decision maker in choosing production testing locations and amounts of testing required in such a way as to minimize the total expected cost of production testing. The fundamental law of production testing will be described which pinpoints the need for reducing in-process testing. In so doing, testing locations and amounts of testing are reevaluated to meet the above mentioned objective. Common methods of accomplishing this objective will be discussed. Finally, examples will be presented that will illustrate how these concepts can be utilized by a decision maker and the resulting advantages to the whole production system will be discussed.

**FP1.1 *Field Experimentation and Small Arms Evaluation,** J. A. STOCKFISCH, *Director, Force Planning and Analysis Office, Department of the Army, Washington, D.C.*

During the fall and winter of 1965 an extensive field experiment was conducted at the US Army Combat Developments Command Experimentation Command for the purpose of evaluating different mixes of small arms—including rifles, automatic rifles, and machineguns in the small infantry unit context. The experiment was designed to provide a large degree of "realism" with particular reference to encompassing the problems of target acquisition. The matrix of the experiment was controlled to balance out possible effects of learning, variations in weather, and other factors. The target systems were instrumented to measure hits and near misses as a function of time. The requirement and the opportunity to conduct the experiment posed a number of interesting questions related to such problems as the development and formulation of measures of effectiveness, the design of the experiment itself, and the fashion in which the data can be used for the purpose of weapon systems evaluation. Highly instrumented field experimentation is a relatively new capability. The role and place of this activity relative to other analytical techniques and means of gathering data will be discussed.

**FP1.2 *A Reformulation of Ground Combat Missions in Mathematical Programming Form,** ROLAND V. TIEDE, *Research Analysis Corporation, McLean, Virginia.*

An attempt to develop general methods for measuring the implications of adding automatic data processing to command control systems for ground combat in terms of cost and effectiveness required for the development of techniques for a marginal effectiveness analysis. One necessary step for such analysis was the reformulation of ground combat missions to permit measurement of marginal mission performance. Examination of typical combat missions identifies three dimensions of "mission space". These are: resources, time, and area control led by a military force. Typical missions are related to a closed continuum of tactical postures ordered on the basis of the relative energy represented by each posture, where energy is associated with un-committed resources and movement rate. Three classes of increasingly severe constraints are identified and associated with decreasing energy. Two objective functions are identified: maximization of rate of advance for high energy postures; and minimization of rate of resource expenditure for low energy postures. The quantifiability of the three dimensions of mission space is examined and difficulties in aggregating different classes of resources and terrain of differing tactical value are recognized. A measure for assessing degrees of control over area by a military force is postulated and tested in a simple mathematical model. Relating mission performance to more highly aggregated measures of combat effectiveness is discussed.

**FP1.3 The Ground Combat Communications Simulator,** DONALD F. BLUMBERG and JAMES F. LOGAN, *Philco-Ford Corporation, TechRep Division, Fort Washington, Pennsylvania.*

The Ground Combat Communication Simulator is a digital simulation. The dynamics of a two-sided ground action are represented by models collectively referred to as the tactical subsystem. The initial conditions define the combatants as an armored division and a mechanized brigade operating in Europe. Reconnaissance and surveillance; information processing and dissemination; fire and maneuver; movement; artillery fire support; and command and control at each echelon (company through division) are portrayed. These models with submodels depicting combat support and combat-service support activities, generate information transfer requirements which form a set of demands placed on the supporting communications system. These demands are translated into messages. The primary functions involved in communications, circuit selection, switching and systems control, are simulated in message processing models. Since the communications system operates in a hostile environment, a model is included which senses the fluctuating stresses resulting from the flow of the tactical action and translates these stresses into a spectrum of system effectiveness conditions. The simulator provides a vehicle for studying problems in areas like: mission effectiveness; weapons systems effectiveness; tactical command/control systems, operational policies and procedures; and communications systems effectiveness. The simulator has been subjected to validation tests and positive results were attained

**FP1.4 A Route Selection Model for a Combat Simulation,** GORDON M. CLARK, *Systems Research Group, The Ohio State University, Columbus, Ohio.*

DYNTACS is a computer played simulation of small-unit combat engagements which describes the combat performance of tank, antitank, and supporting weapons. The simulation will be applied to predict the effect on combat performance of weapon design, tactical employment, environment, and terrain. Potential assault routes are formed by line segments connecting grid points within a sector of the battlefield and leading to the objective. The Route Selection Model selects an assault route in response to enemy and terrain intelligence and the tactical doctrine to be implemented. The tactical doctrine is prescribed as input to the model and is expressed by assigning a difficulty increment and effective range to each type of enemy direct fire weapon likely to be encountered. The concept that provides a basis for comparing assault routes is "relative tactical difficulty". The tactical difficulty is a linear combination of the estimated travel time and the difficulty resulting from being within effective range of intervisible detected enemy positions and potential enemy strong points. The least difficult route is determined by a dynamic programming algorithm. Examples are provided to illustrate the model's sensitivity to changes in detected enemy positions, vehicle mobility characteristics, and tactical doctrine.

**FP1.5 Simulation of Over-the-Beach Logistics Operations,** J. WEINSTOCK, *Consultant, Litton Industries.* and A. DOBIESKI, *TRW Systems, Space Park, Redondo Beach, California.*

A problem which frequently occurs in Military logistics operations is that of combat offloading a cargo ship, over-the-beach, within some minimum time constraint. The equipment which is normally available in such an operation consists of the cargo handling gear of the cargo ship being considered as well as ship-to-shore vessels (lighters), and cargo helicopters. Conventional analysis of the performance capability of various cargo handling systems often considers the productivity of the cargo handling equipment in terms of tons of cargo per hour and more often than not, these analyses neglect the problem of interface between the ship, lighters, and helicopters. Because of these shortcomings, a model was developed to handle the delays inherent in the interface between various independent system links as well as lighter/helicopter queuing, availability, make ready time, start up, and end transient effects. The model is a simulation of the activities and essentially consists of a series of links connected together by nodes which represent the interface between the various parts of the system. This model was programmed in modular form so that subroutines could be added as certain significant problems, such as the end transient condition, became apparent. By considering the cargo in terms of units instead of tons and by the addition of stochasticity to the various random events inherent in cargo handling operations, this model provides a realistic analysis of over-the-beach logistic operations.

**FP1.6 Comparative Analysis of the Utilization of Commercial and Military Transport and Combat Aircraft,** William Grodowitz, *Special Asst. for Program Evaluation, Directorate of Aerospace Programs, Headquarters, USAF.*

A broad comparative analysis is made of the feasibility and economics relative to the utilization of commercial and military transport and military combat aircraft. Utilization refers to the average number of useful hours flown per aircraft per day, standardized on duration of flight or sortie for comparative purposes. The gist of Air Force studies comparing commercial and military utilization rates and associated hourly operating costs is presented. Theoretical methods are provided for determination of optimal efficient utilization levels for combat tactical aircraft. Fundamental differences in mission and operations and pragmatic limitations in utilization are identified and discussed for the categories of aircraft covered.

**FP2.1 Stochastic Allocation Processes,** William D. O'Neil, Jr., *The Bissett-Berman Corporation, 2941 Nebraska Avenue, Santa Monica, California.*

In many actual allocation problems it is not known, in advance, how many allocation opportunites will arise during the course of the process. In this paper, dynamic programming formulations of such processes are presented. Certain of their properties are derived and results of some numerical experiments are displayed. It is shown that such processes are to be found in many military and commercial contexts. Possible extentions are discussed.

**FP2.2 An Alternate Derivation of the Discrete Maximum Principle,** Michael E. Thomas, *University of Florida, Gainesville, Florida.*

The discrete maximum principle is one approach to solving multistage decision problems. The original derivation, which closely paralleled the derivation of the continuous maximum principle, was given by Rozonoer. Extensions were presented by Chang and Kats. Rozonoer's derivation and the later extensions were based on the variational approach. In this paper an alternate approach which is based on the theory of non-linear programming is presented. Using this approach less restrictive sufficiency conditions may be obtained. The current derivation also admits the possibility of constraints on the state variables as well as the decision variables. Finally, convergence criteria are discussed for the solution of the two point boundary value problem which results from application of the algorithm. Analogies are drawn from the solution of similar problems arising in applications of the continuous maximum principle.

**FP2.3 Multichain Markov Renewal Programs,** BENNETT L. FOX and ERIC V DENARDO, *The Rand Corp., 1700 Main St., Santa Monica, California.*

In multichain Markov Renewal Programs the ergodic subchain structure depends on the policy. The paper presents two policy improvement algorithms for solving such programs. The latter are also formulated as linear programs. In the discrete time case, a successive approximation scheme is exhibited.

**FP2.4 Sequential Pattern Recognition Technique,** GEORGE E. LASKER, *Computing Science Department, University of Manitoba, Winnipeg, Manitoba, Canada.*

A new powerful technique for solving complex pattern recognition problems is proposed. This technique enables one to detect and to recognize a particular pattern in the presence of other patterns on the basis of information obtained by sequential analysis of the elements, from which the pattern is made up. The elements, having highest differentially diagnostical value, are analyzed first. These are selected according to a special precalculated program, specifying the optimal strategy of selection at any stage of analysis. The selected elements, as they become sequentially available, are analyzed in order to determine whether the information obtained is already sufficient for the reliable indentification of the pattern or whether further elements have to be examined. Because the selected elements are analyzed sequentially, the information needed for recognition of any particular pattern can be conveniently minimized. The whole pattern can be thus identified by the recognition of its significant part. In practice it means, that for reliable recognition of any particular pattern it is not necessary to examine all the elements from which the pattern is made up, but it is quite sufficient to select and to analyze only a few diagnostically significant elements. In this way the recognition of a pattern can be achieved in the shortest possible time. This is especially convenient when the recognition procedure is carried out automatically by a computer.

**FP2.5 Game Theory Heuristics for Systems Analysis and Design,** JEROME H. N. SELMAN, *Hq, U.S. Army Munitions Command, Dover, and Stevens Institute of Technology, Hoboken, New Jersey.*

The decision processes involved with comparing rival systems involves subjective probability, utility theory, conceptual bridging from data to model, and a decision criterion for optimization. Due to the multiplicity of tasks embedded in the major system missions, and the serendipity-bonus of undesigned-for capabilities and improvizations, present mathematical procedures have proved themselves to be less than satisfactory for systems analysis and effectiveness decisions. This session will survey the decision processes in comparing rival systems and models, explore the appropriateness of Game Theory for arriving at the optimal strategy set of preferences. Emphasis will be addressed to the types of subjective evaluations which must be made inputs to the payoff matrix and the Game Theory criteria available. Audience will participate in evaluating the "better" of two models, to familiarize them with the persistent problems inherent in the weighing of parameters.

**FP2.6 System Decisions from Component Testing,** RICHARD B. WILL, *Aerospace Corporation, San Bernardino, California.*

The general problem treated is how to allocate testing resources to the various components of a system and how to utilize the component testing results in order to draw particular types of inferences about the system. Three types of inferential statements considered enable decisions, respectively, as to whether the system is capable of performing a specified task (Checkout Problem), which components of a defective system are defective (Identification Problem), and what the system failure rate is (Estimation Problem). The criterion for a solution is the minimization of a cost function which reflects probabilities of decision errors, costs of decision errors, testing times, and costs of testing. The solutions of four cost models in the Checkout Problem are derived for a series reliability configuration of the system by placing various restrictions on the probability distribution of the verification time, or time needed to verify that a defective component truly is defective. The first model is also investigated assuming known a priori probabilities of failure for each component. In the more involved parallel configuration, results are obtained for two components when the verification time distributions are exponential. Initially, the set of two-tuples of component testing times is divided into six areas. For each of three sets of parameter values, the corresponding solution area and solution are determined. Then it is shown how the parallel configuration problem for more than two components with fixed testing times can be solved by linear programming. The Identification Problem is similar to the Checkout Problem since, in effect, the aim of both is to identify defective components; however, in the Identification Problem it is assumed that the system is defective. In addition to determination of the optimal testing times, the optimal testing order of the components is found supposing that the components can be sequentially tested, and that cost is a function of utilized testing time, rather than allocated testing time. The purpose of the Estimation Problem is to decide how to allocate component testing time in order to find a minimum-variance and unbiased estimate of the system failure rate when the a priori probability distributions of the component failure rates are known.

**FP2.7 Synergistic Processes,** JOSEPH BODO, *Sylvania Electronic Defense Labs., Mountain View, California.*

Frequently decision processes are based on the cumulative accumulation of evidence from a diversity of sources, where the successive observations manifest in a variety of forms and might exhibit statistical dependence. Some examples are: the accumulation of evidence in a criminal trial, the evaluation of information in surveillance operations, the composition of data base for an intelligence estimate, etc. An attempt is made to establish a unified theory of the underlying synergistic characteristics of this type of processes [i.e. those which create a total effect greater than the sum of a system's parts]. Methods of optimum combination of independent and correlated observations are presented and the asymptotic nature of the resulting processes is pointed out. The effect of timeliness, credibility and other relevant attributes of the input data are discussed in order to relate the synergistic effect to information value measures. The resulting methods will be illustrated by representative examples.

**FP2.8 Scheduling Several Products on One Machine to Minimize Change-Overs,** C. R. GLASSEY, *Operations Research Center, University of California, Berkeley, California.*

Given a finite horizon delivery schedule for n products we wish to schedule production on a single machine to meet deliveries and minimize the number of change-overs of the machine from one product to another. A state space is defined and in it a network is constructed such that the shortest distance through the network corresponds to the minimum number of production change-overs. Certain properties of the optimal path are deduced from the dynamic programming formulation of the shortest route problem, and these properties are utilized in the construction of an algorithm that finds the optimal path. A numerical example illustrates the method.

**FP2.9 Finite Difference Operator in Operational Research,** Q. A. M. M. YAHYA, *Defense Science Organization, Chaklala, West Pakistan.*

The paper shows how the use of a finite difference operator can facilitate the calculations and numerical analysis in operational research models. In particular the replacement policy and inventory models are discussed. The work is connected to a basic result [YAHYA: "On a finite difference operator," *J. Australian Math. Soc.* 6 (1966).]

**FP3.1 Alternative Search Procedures for Revising Investment Portfolios,** KEITH V. SMITH, *Graduate School of Business Administration, University of California, Los Angeles, California.*

A neglected problem within portfolio management is the revising of investment holdings over a period of time. The Markowitz/Sharpe diagonal model for portfolio selection can be extended to an intertemporal basis by using an appropriate transition framework. The framework is an adaptive type of mechanism that reflects current market information in computing "new" efficient portfolios. Three revision procedures, based on this framework, are presented and tested using a population of 150 common stocks over the 1950–1964 period. (1) Complete transitions from existing to target (efficient) portfolios are feasible if the expected gain in portfolio return exceeds the expected cost of making the change, but virtually complete turnover of shares results. (2) A controlled procedure for improving portfolios with only limited turnover is suggested as a compromise. It is an iterative search procedure for finding single-security changes which improve the portfolio characteristics of return and risk. (3) A final procedure is simply to periodically adjust the existing portfolio to the original expectations and efficient set. A cost-effectiveness scheme is developed to compare these revision alternatives.

**FP3.2 OR in Sales Programs: A Case Study,** T. DONALD DIXON, *Research Analysis Corporation, McLean, Virginia.*

This paper describes through a case study the use of operations research in the sales program of a materials handling division of a large corporation. The approach, techniques employed, and results of analyses are described. Fifteen systems for mechanized handling of materials in the client's warehouse are outlined.

Each system is evaluated in terms of cost and effectiveness, the latter measured in terms of degree of mechanization and rate of return on investment. Rates of return are calculated using the discounted cash flow method. Using OR techniques and the team approach, prospective client management is presented with alternative courses of action for a particular expansion program.

### FP3.3 Estimation of a Firm's True Total Investment, Paul T. Gross, Jr., *Texas A. and M. University, College Station, Texas.*

The total net book asset value of a firm often provides a highly inaccurate estimate of the total cash invested in it. This quantity is correctly measured by discounting the remaining cash-flows on all owned assets to the present at their true earnings rates. The degree of error between the book and true investment amounts can be determined from three independent time functions. These are the growth rate of the firm, the shape of the cash-flow pattern attaching to its typical investment, and the schedule of asset depreciation. A technique is developed which establishes the general relation of the firm's total net asset book value to its present value as a function of the growth rate experienced. In the process, the form of the equilibrating depreciation schedule is developed. This technique is then applied to a specific cash-flow pattern and depreciation schedule combination giving a functional relationship between the ratio of net book value to true investment and the growth rate of the firm.

### FP3.4 Integrating Operations Research and the Marketing Information System to Improve the Allocation of Marketing Effort, Stanley F. Stasch, *School of Business, Northwestern University, Evanston, Illinois.*

Unprocessed marketing data taken from a variety of sources does not satisfy the control and decision-making information needs of management. To meet the needs of management, (1) unprocessed marketing data should be used as inputs to a marketing information system (2) which should organize and classify the data for use in certain operations research analyses pertinent to marketing problems. (3) The operations research analyses should transform the data inputs into more significant form and return it (4) to the marketing information system for further organization and classification (5) before being presented to management as the final output of the integrated marketing information-operations research system. An illustration of a multi-product firm selling to a number of geographically dispersed industrial markets is given. The integrated marketing information-operations research system takes input data from a variety of internal and external primary sources, and external secondary sources and utilizes it in two ways. First, seasonally adjusted sales potential information is generated for each product, each customer and each sales territory. This information is compared with up-to-date unit sales and up-to-date personal selling costs for each product, each customer and each sales territory. The sales potential information and the actual sales information are inputs to operations research analyses which evaluate such problems as the optimum number of salesmen to use and the boundaries to be assigned to each sales territory. Second, information concerning delivery time, relationships between speed of delivery and orders lost, and distribution costs are generated for each customer and each sales territory. These data are inputs to operations research analyses which evaluate such problems as the number of distribution centers to use and their location, the transportation media which should be employed, and the combination of physical distribution facilities which will provide the best compromise between speed of delivery and orders lost. These analyses then permit the marketing information-operations research system (1) to compare the actual allocation of marketing effort with market potential, and (2) to evaluate the combination of the number of salesmen, the sales territory boundaries, the number and location of distribution centers, and the transportation media which will most appropriately balance marketing effort with market potential.

**FP3.5 A Simulation of an Automobile Merit Rating Insurance Operation,** THOMAS H. ROCKWELL and ROY L. SAMUELSON, *Systems Research Group, The Ohio State University, 190 West 19th Avenue, Columbus, Ohio.*

The operations of a large automobile insurance company were analyzed and modeled in a digital computer simulation. This simulation is used to determine the relative sensitivity of the company profit-loss picture to changes in key environmental parameters and changes in management policies. Insurance policy classifications are based on three-year accident history, vehicle usage, driver age and class, single or multi-car coverage, and length of service with the company. The resulting 3,672 policy classifications are processed for three years through new business influx, premium generation based on policy classification, bodily injury and property damage accident and claim generation, policy classification change based on accident history, and policy cancellation. Changes in management marketing policy and pricing provided insight into the relative effectiveness of administrative emphasis. Internal functions of the simulation related other key parameters such as cancellations, policy transitions, and premium generation. Self-correcting control functions can adjust for other factors such as inflationary trends to maintain a desired overall profit-loss picture.

**FP3.6 Daily Consumer Shopping Behavior under Probabilistic Gravitation,** RICHARD F. BARTON, *School of Business, University of Kansas, Lawrence, Kansas.*

Models of retail gravitation attempt to describe and predict the flow of consumer traffic (or the volume of consumer purchases) moving from defined geographical areas to alternative shopping centers or stores. Usually, these models relate average traffic (or average purchases) directly to size of the shopping center and inversely to the square (or some other power) of the distance between the geographical area and the center. Huff has fitted (in terms of the power to which distance is raised) such a model to empirical data in a way that generates the proportion of annual traffic (or purchase volume) moving from each area to each center. Considering these proportions as probabilities, expected *annual* consumer traffic, sales volumes, and market shares can be computed for each center, including one or more potential new centers. This paper describes a Monte Carlo simulation that provides distributions of *daily* traffic flow and dollar volume. The simulation model takes as given the above probabilities that shoppers in a locality will gravitate toward particular centers. Parameters of the model are seasonal variations in traffic flow and sales volume, average number of shopping trips per week, daily variations in the probability that a shopper goes shopping at all on any one day, average annual household expenditures by geographical areas, and the distribution of the size of individual purchases. To assist planning of daily operations at both new and existing centers or stores, the model can simulate particular days of the week or particular weeks of the year.

### FP3.7 A Media Selection Model for On-Line Use with a Time-Shared Computer, LEONARD M. LODISH and JOHN D. C. LITTLE, *Sloan School of Management, M.I.T., Cambridge, Massachusetts.*

A media model has been constructed with the following characteristics: The population is divided into market segments, each with its own sales potential and media habits. Media schedules are described in terms of insertions in media vehicles An insertion brings about exposures in the market segments, the number of exposures depending on the audience of the media vehicle and the characteristics of the insertion. The exposures increase a quantity, called the exposure level, in the market segment. A forgetting process causes the retained exposure level to decay with time in the absence of new exposures. The anticipated sales rate to a market segment is a non-linear function of the exposure level. Certain of the inputs required are subjective. An on-line computer program permits the user to insert data, evaluate a given schedule, and if desired, search through a set of media vehicles for a good or optimal schedule. A dynamic programming option permits optimization in small problems with linear costs. A heuristic program is available for larger problems.

### FP3.8 SCAN (schedule analysis) and RAPP (resource and project planning), A System Designed for Production Scheduling and Progress Control in a Multi Project and Multi Resource Situation, W. J. LEYDS, *Philips Telecommunication Industries, Huizen, Netherlands.*

SCAN and RAPP is an effective system where projects are: executed concurrently; dissimilar; often interrelated; and disturbed frequently by external or internal unforeseen changes. It is an off-line system. It can be run in two weekly cycles of updating and reporting or more frequently. It performs the following operations: analysis of network schedules of new projects; analysis of schedules being executed for which changes have been introduced in the planning; loading activities into resources using float to level off fluctuations in capacity needed; printing a survey per project and per resource and reports for top management. No calculations with regard to probability of end-dates or economical aspects are made. Delivery times are shortening and becoming more reliable whilst management is adapting itself to network analysis and progress control by this system. It is effective because it complies with the practical needs of management of all levels. It is used by Philips Telecommunication Industries in Huizen since January 1, 1966, and has been introduced in other plants Limits to the system are 250 resources and 120,000 activities.

**FP4.1 A Reference-Connecting Technique for Automatic Information Classification and Retrieval,** MARJORIE J. GREENE, *Operations Evaluations Group, Center for Naval Analyses, 1401 Wilson Blvd., Arlington, Virginia.*

A recent study of command information flow associated with the Dominican Republic coup of April-May 1965 introduced an analytical tool for identifying deficiencies in the flow and use of information which appears to have considerable potential as a general technique for information retrieval. Naval messages are associated with each other through their formal references in a manner analogous to the concept of "joining" as defined in a recent publication in directed graph theory by Harary, Norman, and Cartwright (*Structural Models*). "Reference-connected sets" are then constructed from message traffic dealing with the coup and are found to uniquely identify operational events during the crisis. Such sets (and subsets if further refinement is desired) can be obtained in real-time and a very simple method is demonstrated which automatically classifies messages as they enter the system. This technique, if applied to a library system, avoids both the problem of describing the subject covered in a document and the problem of integrating new subject matter into a predetermined classification code. It is a user-oriented system which combines static coupling methods used in the Technical Information Project at MIT and converts them into a dynamic process for both classification and retrieval. Thus, it concentrates on the evolution of the subject as represented by referenced documents upon which any "new" information is based and it has the additional advantage of reflecting the information flow among scientists in any field.

**FP4.2 Normal Text Information Retrieval-Management and Line Use Within IBM,** JOSEPH J. MAGNINO, *IBM Research Center, Box 218, Yorktown Heights, New York.*

As Management Information Systems develop, and are used, it becomes more apparent that sophisticated information retrieval file organization, and inquiry techniques, are important. However, not all I.R. systems are oriented to one user, i.e. Management, and the normal text information retrieval system described is an example of a dual-purpose system. The description of the IBM 360 file design and organization, as well as the operational systems used, highlights the weakness and strength of designing for two masters, management and line. The two masters approach requires merging the IBM 360 Current Information System and the IBM Generalized Information System into an effective dual-purpose package. Operational results of this approach are discussed.

**FP4.3 A Mathematical Programming Approach to Automatic Interceptor Selection in Command/Control Systems,** C. FREMONT SPRAGUE III, *Operations Research, 3045 Rosecrans St., Suite 300, San Diego, California.*

In air defense systems, a problem in interceptor selection arises when more than one interceptor is available to intercept aircraft closing an area to be defended. As air defense systems become automated, the accompanying automation of the interceptor selection problem requires the retrieval and processing of information that is relevant to this decision process. This paper presents a computationally feasible mathematical representation of the interceptor selection decision-making process. The method is based on linear programming, and is concerned with the minimization of a linear function of two variables; penetration, which is the distance the target moves along its projected straight-line course before being intercepted, and the fuel consumption required by the interceptor to complete its intercept. The minimization must be carried out within the constraints imposed by the penetration-fuel consumption "trade-off" curves of each interceptor being considered. A method for computing these curves, based on operational data expressing the rate of fuel consumption as a function of speed and the equations for the geometrical relationships inherent in a "collision-course" type intercept, is presented. The constraint set for the linear programming procedure is determined by taking the convex hull of the union of the penetration-fuel consumption curves for all the interceptors which are candidates to make the interception.

**FP4.4 Information Theory Applied to Maintenance Data,** HARALD R. LEUBA, *ARINC Research Corporation, 2551 Riva Road, Annapolis, Maryland.*

This paper describes the results of an application of information theory concepts as a "correlational tool." The purpose of the study was to determine which portions of verbal malfunction reports are most useful to maintenance personnel in the performance of maintenance, and which aspects of the maintenance situation are most highly related to total maintenance efficiency. The major findings were: (1) that variability in symptom reporting (an operator characteristic) is a major determiner in the probability of successful equipment performance following maintenance, (2) that maintenance personnel have access to considerably more information than that contained in the symptom, but (3) that they do not use this information as efficiently as they might and (4) that the information in verbal malfunction reports is non-uniformly distributed across those reports. The results of this investigation demonstrated the existence of structure in maintenance data, and the practicality of information theory as a tool for analyzing data and quantifying effects. The analyses lead to a number of observations which appear to be representative of Air Force maintenance in general, and have important implications for maintenance evaluation and maintenance efficiency. Both operators and maintenance men are contributing significantly and presumably correctably to system ineffectiveness. The report concludes with a series of recommendations for implementation and evaluation.

**FP4.5 Personality Theory and Operations Research,** LAURENCE KASHDAN, *North American Aviation, Inc., 11711 Florence Ave., Santa Fe Springs, California.*

The structure and dynamics of four major theories of human personality are reviewed, comparisons are made with typical trade-off models in system engineering, and the personality theories are shown to share a common basis: descriptions of individual optimization behavior. Each viewpoint postulates interacting structures which strive to maximize their own "goodness" or effect. But the dynamics of interaction between the structures is a trade-off which prevents maximization. Psychoanalytic schools describe interactions between instinct and reality. Learning/conditioning theories assume a process of reinforcement and extinction following a diminishing marginal process. Social psychology defines dependent external and internal environments with respect to the individual. Existential/self theories postulate a sought structure interacting with an obtained structure. A single model of individual optimization behavior is proposed which bridges these viewpoints. "Normal/abnormal" is defined with reference to the sub-optimizations attained by the individual in employing limited resources. Capabilities and limitations of psychotherapy are discussed in terms of opportunity costs and resource utilization. This analysis is distinguished from a "theory" of behavior. Rather, paraphrasing Ackoff, it defines a single phenomenon which is viewed in different ways by various disciplines, both within and outside of the behavioral sciences.

### FP4.6 Some Properties of a Normative Planning Model, MARK ALFANDARY-ALEXANDER, *U.S. A.E.C., Washington, D.C.*

An analytical model designed for normative planning has been previously described (*Operations Research*, v.14, Supp.1, 1966; v.13, Supp.2, 1965). This model allocates resources on the basis of SEU (subjective expected utility) maximization; the determination of the utility functions is made with the aid of some of Bridgman's and von Neumann's concepts of measurement. The utilities used are marginal values unique up to at least hypermonotone transformations, i.e. based on an interval scale. Some useful properties of this model are presented. They include (a) engagement of the ordered marginal characteristics of the values obtained with the marginal pattern of the resource allocation algorithm used, (b) pragmatic economy of effort as far as the executive is concerned (important for the practical introduction of the model and its implementation), and (c) maximization of utility with respect to goal-accomplishment rather than with respect to resource expenditure, i.e. resource usability is considered as a controlling constraint but not as the mainspring of utility generation—the latter depends on goal accomplishment.

### FP4.7 Assumptions in Economics: An Operations Research Approach, RICHARD B. HOFFMAN, *Center for Planning and Development Research, University of California, Berkeley*, and CHARLES SCHOTTA, JR., *Department of Economics, University of California, Davis, California.*

This paper examines several representative economic models, selects a set of assumptions underlying these models, and uses as criteria goals for which the models are constructed. The first model to be evaluated is a simple variant of the Keynesian model. The sector singled out for emphasis here is the labor market in which the assumptions implying the constancy of the real wage is of primary interest. For example, it appears that if wages are bounded by a monotonically, nondecreasing function, the stochastic nature of the process will be such that prices and wages must increase over time. Within the context of the short run, comparative static model which we examine, it would appear that there exists a fundamental inconsistency between the assumptions and the goals implied by the literature in which the variant of the model we examine is imbedded. The second model is a modified Patinkin-type system, (*Money, Interest and Prices*, Harper & Row, 1965) in which our concern is to evaluate the equilibrium conditions (and the underlying assumptions) in terms of the probability that the system (and/or any individual within the system) will be in an equilibrium state at any given point in time. We are currently applying our technique to several existing models of asset portfolio choice, e.g., Markowitz, Sharpe, and Farrar, to certain problems related to "bliss points" in quadratic preference functions, and to certain aspects of a capital theory, e.g., Solow, Lerner, Kaldor. Our conclusions allow us to suggest possible inconsistencies which appear to exist between the necessary assumptions for certain results in each model and a set of subjectively-determined goals or objectives for each model. In some cases we are able to restate the assumptions in order to eliminate the inconsistency, in others we are able to list the objectives which could be consistent with the assumptions of the models.

**FP4.8 Administration of Criminal Justice,** RICHARD B. HOFFMAN, *Center for Planning and Development Research, University of California, Berkeley, California.*

What are the types of information which are required to obtain an approximation of society's objectives as they are broadly described for the "system" of criminal justice? To do this, we are required to analyze the broad goals of the "System" and to determine the degree to which there exist incompatabilities in objectives. This leads inevitably to examining the relationship of the components of the system, and consideration of possible means of ameliorating aberrations which are introduced into the system. We need to determine the types of information which are presently used in the administration of criminal justice and the conditions under which this information is obtained in terms of source, content, and purpose. In view of the questions which are implicit in the first paragraph, we need to determine the precise types of information which are minimally required to accomplish each of the major tasks of the system of justice: *viz.* prevention, suppression, apprehension, trial, treatment, punishment. Finally, the "systems" approach to a study of the administration of criminal justice involves the following considerations: (1) What are the present problems of obtaining the types of information which are necessary for effective utilization? (2) What are the problems of determining the objectives of the real system, and can the real system be described? (3) What are the problems of obtaining the cooperation of existing agencies? (a) Such an approach may alter their present roles, functions, and goals. (b) The agencies may not be presently capable of completing their newly assigned tasks. The approach outlined above is also capable of being applied to a specific sub-system of criminal justice; e.g., it can be used for a meaningful study of the police, probation and parole agencies, and the other agencies which provide for the administration of justice.

# *Society Affairs*

## THE ORSA COUNCIL MEETING

The Thirtieth Meeting of the Council of the *Operations Research Society of America* was held on 18 October 1966, during the ORSA meeting in Durham, North Carolina, with John F. Magee, President presiding. The following items from the Council Meeting are reported:

*FUTURE ORSA MEETINGS:*

| No. | Dates | Location | Chairman |
|---|---|---|---|
| 32 | November 1–3, 1967 | Chicago | T. E. Caywood<br>*Caywood-Schiller Associates*<br>*401 North Michigan Avenue*<br>*Chicago, Illinois 60611* |
| 33 | May 1–3, 1968 | San Francisco | F. L. Weldon<br>*Matson Research Corp.*<br>*215 Market Street*<br>*San Francisco, Calif. 94105* |
| 34 | November 6–9, 1968 | Philadelphia | Leo Rogin<br>*Air Warfare Research Department*<br>*NADC*<br>*Johnsville, Pennsylvania 18974* |
| 35 | Spring 1969 | Denver | George W. Morgenthaler<br>*The Martin Company*<br>*Box 179*<br>*Denver, Colorado 80201* |

*MEETINGS COMMITTEE:* The *Chairman* reported the Committee was considering New Orleans as the site for the Fall 1969 meeting and Washington, D. C. for the Spring of 1970. Completion is anticipated of a meetings manual for use of future chairmen of this committee.

*EDUCATION COMMITTEE:* The Council encouraged the Education Committee to prepare a plan of action for organizing a lecture program to universities and/or student groups, including definite suggestions with regard to the cost of such a program.

*LANCHESTER PRIZE COMMITTEE:* The Council approved the award of the Lanchester Prize to Michel L. Balinski for "Integer Programming: Methods, Uses, Computation," which appeared in *Management Science*, Volume 12, November 1965, and to Rufus Isaacs for "*Differential Games*" published by John Wiley and Son, Inc., New York, 1965. In the future, in addition to the monetary value of the prize, there will be a certificate and a medal (instead of a plaque as had been the custom).

*SECTIONS COMMITTEE:* The Chairman requested the assistance of an enlarged committee to handle geographical sections. The Education Committee could assist with student sections. The Council authorized establishment of the Rocky Mountain Section of ORSA. The Chairman of the Sections Committee will formulate recommendations to the Council on purposes for organizing sections, financial management, and on responsibilities of sections to the purpose of the Society.

*RECOGNITION COMMITTEE:* The Committee is continuing its work towards a recommendation to the Council concerning a suitable way of recognizing good work in OR, aside from the Lanchester Prize.

*PUBLICATIONS COMMITTEE:* The Council approved proposed contract with Kraus Reprint Corporation for reprinting certain volumes of OPERATIONS RESEARCH, authorizing the Editor of OPERATIONS RESEARCH, with the concurrence of the Publications Committee, the President and Secretary of the Society, to add later volumes to the agreement as it becomes desirable.

*IFORS:* Proceedings of the *Fourth International Conference* will be published. The Council expressed its appreciation to Martin L. Ernst for his outstanding work as *Chairman* of the Program Committee for the Fourth International Conference on Operations Research. The Council expressed its appreciation to William Marcuse and his Committee for their outstanding contribution to the success of the *Fourth International Conference on Operations Research*; their work achieved a high standard of efficiency and attention to detail that made the administrative affairs of the Conference so smooth as to be almost unnoticeable to the conferees, and thus brought great credit and much appreciation to the Operations Research Society of America.

*AAAS:* The Council discussed briefly the continuing activities of the sections of AAAS in which ORSA participates.

The Council authorized the *Secretary* to take the necessary steps to present to the Membership the proposed amendment to the Constitution (Article VII) concerning the composition of the Council, namely, to include with the Officers the three most recent past *Presidents* of the Society. To be effective 1 September 1967

*CONFERENCE BOARD OF THE MATHEMATICAL SCIENCES:* The Council has accepted the invitation of the *Conference Board of the Mathematical Sciences* to become an Associate Member. The Council authorized the *President* to appoint an ORSA Representative. The ORSA Representative was authorized to negotiate a mutually agreeable financial contribution to the Board.

*NOMINATIONS:* The following slate has been announced by the Nominating Committee (biographies and ballots are being mailed to the Membership separately):

| | |
|---|---|
| *Vice-President* (President-Elect) | Joseph H. Engel |
| | David B. Hertz |
| *Secretary* | David Katcher |
| | Robert E. Machol |
| *Treasurer* | Thomas E. Oberbeck |

*Councilmen* (2)
(3 years)

David M. Boodman
Georges Brigham
Ernest Koenigsberg
C. E. Lemke
Martin K. Starr
Foster L. Weldon

(In addition, as a result of nomination by petition, the following will appear on the Ballot: Leslie C. Edie candidate for *Vice-President* (President-Elect); Richard E. Beckwith and David S. Stoller candidates for *Councilmen.*)

*ORSA MEMBERSHIP:* As of 30 September 1966, there were 1851 *Members*, 3152 *Associate Members*, and 546 *Student Associate Members*, for a total membership of 5,549.

*NEW MEMBERS:* The Membership Committee reported its nominees for full Membership in theSociety. A list of new Members is shown:

Elected Members at 30th National Meeting

Arnold, George Lewis
Benington, Herbert D.
Berman, Gerald
Blackwell, Clell Miller
Boubli, Elie J.
Brinckloe, William Draper
Briskin, Lawrence E.
Brock, Paul
Bryson, Marion R.
Burch, George Wiley
Carty, Robert Thomas
Clancy, Gerald Patrick
Clifford, Joseph Michael
Collins, Frank Edward
Crowston, Wallace B. S.
Davies, Alan Dunbar
Diener, Donald Milton
Dougherty, Elmer L.
Downer, Charles B.
Durrenberger, John Anthony
Faragher, William Edward
Fennema, Frederick F.
Fish, Robert Alden
Forry, K. E.
Garcia, John David
Graybeal, Bernard Burkett, Jr.
Guess, A. Lawrence
Guggenheim, Allen
Haake, James Walter
Jackson, Leon Frederick
Jaffe, Herbert
Jaiswal, Narendra Kumar
Jones, George Paul
Karasyk, Leonard
Kaspar, Hans
Kennedy, William Bruce
Kirby, Michael J. L.
Kortanek, Kenneth Otto
Kriebel, Charles H.
Lee, Alec M.
Lloyd, Laurance Henry
Marciano, Richard Alfred
McMillan, L. K., Jr.
Moonan, William Jane
Moy, William Arthur
Mullick, Satinder Kumar
Nathan, Gad
Nelson, Rosser T.
Ness, David Norman
O'Neil, William Daniel, Jr.
Powell, John Coleman
Ralls, Rawleigh Hazen
Reichertz, Paul Peter
Rodden, Robert Morris
Rosenthal, Ralph Ottmar
Rotkin, Israel
Sargeant, Robert Allan
Schilling, Donald Lee
Schoman, Charles Martin, Jr.
Soland, Richard Martin

Solem, Anson Donald
Sorenson, Richard Charles
Stowens, Bernard H.
Tachmidji, Alexander John
Thomas, R. Emerson
Thompson, John Everett
Trinkl, Frank Herman
Umen, Andrew Jay
Vandiver, Edgar Bishop, III
Vilaplana, Jose Perez
Wadey, Walter G.
Wagner, W. Henry
Weinbrenner, George Ryan
Whiton, Justin C.
Williams, Albert Charles
Wirt, Charles Alvin
Woods, Walter Max
Wrathall, Edward
Zehna, Peter William
Zindler, Richard Eugene

Joseph H. Engel
*Secretary*

## TREASURER'S REPORT

Holloman AFB, New Mexico
February 27, 1967

Following is a statement of Cash Receipts and Disbursements of ORSA for the calendar year 1966. The report of the auditors accompanies this statement. A breakdown into two columns is used, with International Abstracts in Operations Research receiving special consideration. The method of statement is on an explicit cash basis with major obligations listed by note.

Thomas E. Oberbeck
*Treasurer*

* * * * *

## AUDITOR'S REPORT

The Operations Research Society of America,
Baltimore, Maryland.

We have examined the statement of cash receipts and disbursements of The Operations Research Society of America for the year ended December 31, 1966. Our examination was made in accordance with generally accepted auditing standards, and accordingly included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances.

In our opinion, the accompanying statement (pages B-102–B-103) presents fairly the cash receipts and disbursements of The Operations Research Society of America for the year ended December 31, 1966.

Baltimore, Maryland
February 16, 1967.

Lybrand, Ross Bros. & Montgomery

## THE OPERATIONS RESEARCH SOCIETY OF AMERICA
## STATEMENT OF CASH RECEIPTS AND DISBURSEMENTS

For the year ended December 31, 1966

| | *Regular* | *International Abstracts in OR* |
|---|---|---|
| Receipts: | | |
| Members' dues | $54 062 | $13 699 |
| Subscriptions | 38 460 | 18 086 |
| Advertising, less commissions | 11 619 | |
| Sales of back issues (including bulk sale of Vols. 5–13) | 9 284 | 1 923 |
| Interest | 4 854 | |
| TRANSPORTATION SCIENCE, net after $1,075 organization expense | 6 977 | |
| Royalties | 2 017 | |
| Meetings, net | 7 791 | |
| Mail list, net | 449 | |
| Miscellaneous | 253 | |
| | 135 766 | 33 708 |
| Disbursements, as annexed | 104 134 | 30 864 |
| Excess of receipts over disbursements | 31 632 | 2 844 |
| Cash at beginning of year | 125 511 | 17 028 |
| Cash at end of year | $157 143 | $19 872 |
| Represented by: | | |
| Petty cash funds | 1 510 | 675 |
| Demand deposits | 37 094 | 19 197 |
| Deposits with federal savings and loan associations and bank | 118 539 | |
| | $157 143 | $19 872 |
| Portions of the cash balance are reserved as follows: | | |
| Unearned subscriptions: | | |
| Volume 15 (OR) to be issued in 1967 | 51 000 | |
| Volume 7 (IAOR) to be issued in 1967 | | 17 000 |
| TRANSPORTATION SCIENCE | 4 600 | |
| Guarantee to publisher of the Society's series "Publications in Operations Research" | 6 000 | |
| Printing and binding 1966 Directory | 5 400 | |
| Third International Symposium | 5 300 | |
| IFORS dues for 1966 | 1 400 | |
| Unpaid reimbursement vouchers and bills | 1 000 | 500 |
| | $74 700 | $17 500 |

## THE OPERATIONS RESEARCH SOCIETY OF AMERICA
## DISBURSEMENTS
For the year ended December 31, 1966

| | *Regular* | *International Abstracts in OR* |
|---|---|---|
| Journal printing costs | $48 181 | $18 188 |
| Editorial and other expenses | 9 795 | 1 861 |
| Salaries and fees | | 7 797 |
| Managerial services | 27 070 | 1 500 |
| Bulletin printing | 5 745 | |
| IFORS dues for 1965 | 1 437 | |
| Publications in OR | 543 | |
| Third International Symposium | 358 | |
| Travel expense | | 212 |
| Council and officers' expenses (Note) | 189 | |
| General society expenses | 1 380 | |
| Lanchester prize | 1 000 | |
| Supplies, materials, etc. | | 1 305 |
| Auditing | 500 | |
| Committee expenses (Note) | 2 699 | |
| Sections expense (Note) | 5 213 | |
| Miscellaneous | 24 | |
| Total disbursements | $104 134 | $30 864 |

Note: Details of council and officers' expenses and committee expenses are:

| Council and officers' expenses: | |
|---|---|
| President | 90 |
| Secretary | 99 |
| | $189 |

| Committee expenses: | |
|---|---|
| Membership | 122 |
| Prize | 204 |
| Nominating | 228 |
| Publication | 68 |
| Sections | 618 |
| Education | 1 459 |
| | $2 699 |

| Section expenses: | |
|---|---|
| Military Applications | 1 446 |
| Transportation Science | 897 |
| Cost Effectiveness | 2 870 |
| | $5 213 |

## NOMINATIONS FOR THE 1966 LANCHESTER PRIZE

The screening of books and papers for the Lanchester Prize will be carried out in a new way this year. Instead of having all the possible sources examined by a large number of screeners, the committee will consider only those books and papers which are placed in nomination. This is a call for such nominations. To be eligible for the 1966 Lanchester Prize a book or paper must meet the following requirements: (1) It must be on an operations research subject, (2) It must have been published in the calendar year 1966, (3) It must be written in the English language, and (4) It must be free of security classification.

Publication may be in any form. Journal publication may be in any journal. Each book or paper will be judged on the following criteria: (1) The magnitude of its contribution to the advancement of the state of the art of operations research, (2) The originality of its ideas or methods, (3) New vistas of application opened up by it, (4) The degree of unification or simplification of existing OR theories or methods it achieves, and (5) Expository clarity and excellence.

Nominations should be sent to DR. B. A. SCHOOMER, Secretary, Lanchester Prize Committee, *American Stock Exchange, 86 Trinity Place, New York, New York 10006.* It is not necessary to make an elaborate nomination. All that is necessary is to send in the Title, Author(s), and place of publication. The committee will then make a careful review of each book or paper nominated. Anyone is eligible to make nominations.

GEORGE E. KIMBALL, *Chairman*
Lanchester Prize Committee

## REPRINTS OF OPERATIONS RESEARCH

Reprints of volumes 5–12 of Operations Research, the Journal of the Society, are now available, according to the Kraus Reprint Corporation, 16 East 46th Street, New York, N.Y., 10017. With this new printing, a complete set of back issues is available as follows:

*OPERATIONS RESEARCH*

Journal of the operations Research Society of America

Volumes 1–12, 1953–1964, cloth $324.00, paper $294.00

| | | |
|---|---|---|
| Vols. 1–4 | per volume | paper $21.00 |
| Vols. 5–10 | per volume | paper $25.00 |
| Vols. 11–12 | per volume | paper $30.00 |

## TRANSPORTATION SCIENCE

The Publications Committee of the Operations Research Society of America is pleased to announce that the Society will begin publication in 1967 of a new quarterly journal: *Transportation Science.*

Initially proposed by the ORSA Transportation Science Section under the leadership of DENOS GAZIS, *Chairman,* and LESLIE EDIE, *Past Chairman,* the new journal will be the publication of this Section.

The *Editor* will be ROBERT HERMAN of the General Motors Research Laboratories, Warren, Michigan. He will be supported by a board of *Associate Editors* representing an appropriately wide set of technical, functional, and geographic interests; the membership of this group will be announced later.

The journal will have a distinctive format, but it will be consistent with the Society's other journals, *Operations Research*, the *Bulletin*, and *International Abstracts in Operations Research*, and it will also be composed and printed by the Waverly Press, Inc., of Baltimore, Maryland.

Individuals who are members of ORSA may subscribe to *Transportation Science* at a special rate of $6.00 per year; for others the rate will be $9.00 per year.

Orders should be addressed to *Business Manager, ORSA, 428 East Preston St. Baltimore Maryland 21202.*

## COST EFFECTIVENESS SECTION

The C-E Section *Newsletter*, published periodically, has been mailed to members of the Society. Invitations to join the C-E Section have been extended to all members of the SOCIETY in the January, 1967, issue. No additional cost is involved. Write to J. A. JOSEPH, *Secretary, Cost-Effectiveness Section, ORSA, 7916 Lynbrook Drive, Bethesda, Maryland 20014.*

## PROPOSED HEALTH APPLICATIONS SECTION

At the October Meeting in Durham, a *Health Applications Section* was advanced as a logical follow-on to the developing Society interest in applying operations and systems analysis approaches to the solution of community problems that degrade the quality of our national life. The idea has been given official encouragement as well as membership support.

Members of ORSA who wish to register their active interest in supporting a *Health Applications Section* are encouraged to write to JOHN R. HALL, *Bureau of Health Manpower, Public Health Service, 800 North Quincy Street, Arlington, Virginia 22203.* In New York at the May, 1967 ORSA Meeting, a discussion will be scheduled to prepare for the formal steps required to achieve active Section status.

## ORSA STUDENT CHAPTER (BERKELEY)

Officers of the student group for Fall, 1966, were STEPHAN P. BRADLEY, *Acting President*; K. G. MURTY, *Secretary*; and PHILIP D. ROGERS, *Treasurer*. During the 1965–66 Academic year a regular program of meetings with visiting speakers was held, a policy continued into 1966–67. Two joint Berkeley-Stanford symposiums were held during the 1965–66 academic year. The Chapter has referred a number of papers for scientific journals. On January 18, 1967, Officers for the present year were elected. They are: ROBERT SANDERSON, *President,* ROBERT HARRIS, *Vice President,* KATTA MURTY, *Secretary,* and ROBERT MIFFLIN, *Treasurer.* For further information: *Secretary, Student Chapter, Operations Research Society of America, Operations Research Center 3115 Etcheverry Hall, University of California, Berkeley, California 94720.*

## NEW ADDRESS FOR ORSA BUSINESS MATTERS

Please address all correspondence for business affairs, including new memberships, address changes, inquiries, and the like, to Buisness Manager, ORSA, 428 East Preston Street, Baltimore, Maryland 21202.

# *News and Announcements*

## OPERATIONS RESEARCH COUNCIL

The Washington Operations Research Council, now in its sixth year and serving over 700 members of the Washington OR/MS community, announces its officers and trustees for the Program Year, 1966–67. *President:* JOHN HONIG of the Weapons Evaluation & Control Bureau of the Arms Control & Disarmament Agency. *President-Elect:* WINSTON RILEY, III, CEIR, Bethesda, Maryland. *Secretary:* JOANN LANGSTON, Technical Operations/CORG, Fort Belvoir, Virginia. *Treasurer:* EUGENE VISCO, Research Analysis Corporation, McLean, Virginia. *Trustees:* WALTER DEEMER, Arms Control & Disarmament Agency, Washington, D.C.; JOSEPH ENGEL, Center for Naval Analyses, Arlington, Virginia; WALTER HAHN, Environmental Science Services Administration, Rockville, Md.

## OPERATIONS RESEARCH AROUND THE WORLD MEETINGS

Some coordinated meetings that extend around the world are being held in 1967. Collectively, these meetings should constitute by far the most substantial operations research conference ever held, both in program and attendance. These meetings are, respectively, sponsored by the *Operations Research Society of Spain*, the *Operational Research Society of India*, the *Operations Research Society of Japan*, and *The Institute of Management Sciences* (TIMS).

The schedule of the meetings is: (1) July 28 through August 2, Madrid, Spain. (2) August 7 through August 10, Delhi, India. (3) August 14 through August 18 (extended to August 18), Kyoto and Tokyo, Japan. (4) August 22 through August 25, Mexico City, Mexico (the 14th International Meeting of TIMS).

*Each meeting is the separate responsibility of its sponsor.* There is, however, some coordination, which occurs through the Meeting Coordinator. The programs and travel arrangements are under his direction. He should be contacted about participation in one or more meetings. One exception is that persons attending the Mexico meeting should make all of their arrangements through TIMS (A. CHARNES of *Northwestern University* and W. W. COOPER of *Carnegie Institute of Technology* are *Co-chairmen* of this meeting). Another exception is that persons attending only the meeting in their residence country should deal directly with the OR society for that country.

Potential attendees are invited to submit abstracts or papers. Upon acceptance, invitations will be extended to the authors to present their papers. Also, persons who are able to attend and are available to organize and/or chair sessions, to be discussants, panel members, etc. should contact the Coordinator. The beginning of March was the deadline for submission of papers to appear on the official programs for the Spain, India, and Japan Meetings. However, supplementary programs (for Spain, India, and Japan) may be organized for papers that are submitted later.

Membership in an operations research society is not necessary for attending or participating in a meeting.

As presently envisaged, every attendee is expected to provide his own travel support. For persons attending all of the Spain, India, and Japan Meetings, reduced airline fares should be available (from group travel).

For further information, write John E. Walsh, *Meeting Coordinator, Operations Research Around the World Meetings, % System Development Corp., 2500 Colorado Ave., Santa Monica, California 90406.*

## OPERATIONAL RESEARCH SOCIETY (U.K.)

The Proceedings of the National Conference on *Operational Research in the Social Sciences*, held at Cambridge, England, in 1964, have been edited in a uniform format by J. R. Lawrence, and were published in September, 1967, by Tavistock Publications Limited on behalf of the Operational Research Society.

The 1967 Conference of the Operational Society will be held at Exeter University, September 24–29, 1967. The Theme of this meeting is "Decision Taking." Sessions will be devoted to decisions in government, the social services and industry both at the policy and mangement control levels. *Conference Director* is J. A. Faulkner, *National Coal Board Coal House, Lyon Road, Harrow, Middlesex, England.*

A series of eight short courses in operations research, designed to acquaint the industrial employee with techniques and methods, has been planned for the 1967 season by the Society. Topics include (1) Appreciation of operations research, (2) Basic Mathematics, (3) Methods and Techniques, (4) Economics, (5) Mathematical Statistics, (6) Management functions, controls and services, (7) The O.R. Project, and (8) Computers. These courses will be given at selected university locations.

In related notes, the following news. A. Battersby, senior lecturer, *Cranfield College of Aeronautics,* has been appointed to a senior research fellowship in management at *Balliol College,* endowed by the Institute of Directors, to be held jointly with a research fellowship at the Oxford Centre for Management Studies.

The Operational Research Society regularly publishes lists of operations research courses given in England.

For information, write Margaret Kinnaird, *Operational Research Society, 64 Cannon Street, London, E.C.4.*

## CANADIAN OPERATIONAL RESEARCH SOCIETY

The Ninth Annual Conference of the Canadian Operational Research Society will take place May 11–12, 1967, in Ottawa, Ontario. The Conference will feature a special session on O.R. in the management of resources. Enquiries should be directed to the *Chairman of the 9th CORS Conference, P.O. Box 120, R.R. No. 1, Ottawa, Ontario, Canada.*

## OPERATIONAL RESEARCH SOCIETY OF NEW ZEALAND

Inaugurated in July, 1964, the Society now has nearly 100 members. The *Secretary* of the New Zealand Society is R. C. Wheeler, *% State Services Commission, P.O. Box 8004, Wellington, New Zealand.*

## INDIAN SYMPOSIUM ON O.R.

The National Institute of Sciences of India and the Ministry of Defense, Research and Development Organization held a symposium on Operations Research, November, 1966. For further information, S. S. SRIVASTAVA, *Director, S.E.G., Room 110, "H" Block, D.H.Q., P.O. New Delhi, 11, India.*

## FRENCH O.R. CONFERENCE

The Sixth National Meeting of *L'Association Francaise d'Informatique et de Recherche Opêrationnelle* will be held at Nancy, France, May 22–24, 1967. Address all inquiries to: AFIRO, *25 rue Jasmin, 75, Paris, France.*

## NATO CONFERENCE ON LARGE SCALE PROVISIONING SYSTEMS

This conference will be held at Athens, September 4–8, 1967. Multi-echelon supply systems will be stressed. For information, write *Conference Director, Monsieur Le Commissaire general de la Marine,* JACQUES FERRIER, *Direction du Commissariat de la Marine, 83—Toulon Naval, France.* The U.S. source of information is MARVIN DENICOFF, *Logistics and Mathematical Statistics Branch, Department of the Navy, Washington, D.C. 20360.*

## U.S. GOVERNMENT GRANTS (FULLBRIGHT-HAYES ACT)

U.S. Government grants for University Lecturing and Postdoctoral Research for the years 1967–8 have been announced. Awards are by field of interest and country. For application forms, write to *Committee on Internation Exchange of Persons, Conference Board of Associated Research Councils, 2101 Constitution Avenue, Washington, D.C. 20418.*

## WINSTON CHURCHILL FELLOWSHIPS

The Winston Churchill Memorial Trust, with separate trusts in England, Australia, Canada, New Zealand, and the U.S.A., provides awards for travel for those in different occupations. The fellowships, not normally awarded solely for formal study, are varied by occupation (e.g., Mining, Social Service, Police, etc.) yearly. The value of the fellowship is a basic grant covering return air fare plus daily living expenses, accident insurance, etc.; grants normally cover a twelve month period. Completed applications must reach the office below by November of each year. For further details and application, write *The Winston Churchill Memorial Trust, 37 Charles Street, London, W.1.*

## NATO FELLOWSHIPS IN OPERATIONS RESEARCH

Since 1962 the NATO Science Committee has sponsored operations research apprenticeships for graduate students who are citizens of NATO nations. The normal assignment is for two years. Each apprentice receives from NATO funds an allotment of $4,000 per year together with travel expenses to a maximum of $1,000 round trip to his place of work. Applications should be made for the year following by December 31st. Apprenticeships start in September annually. For applications, write, *The Assistant Secretary General for Scientific Affairs, North Atlantic Treaty Organization, Place du Marechal de Lattre de Tassigny, Paris XVIe, France.*

## OTHER MEETINGS AND COURSES OF INTEREST

"The Fall Joint Computer Conference" will be held November 14–16, 1967, at the Convention Center, Anaheim California. HARRY T. LARSON is *Technical Program Committee Chairman, P.O. Box 457, Costa Mesa, California 92627.*

A summer conference entitled "Operations Research Methods for Industrial Engineering Faculty," will be conducted by the University of Florida August 21 through September 8, 1967. The Conference is funded by the National Science Foundation. *Director* is M. E. THOMAS, *Department of Industrial and Systems Engineering, University of Florida, Gainesville, Florida 32601.*

The Austrian Council for Efficiency (ÖKW) will arrange in collaboration with the International Computation Center an international congress for Network Analysis, May 22–25, 1967, at Vienna. The fee is $80. For information, write *Committee "INTERNET," ÖKW, Eschenbachgasse 11, A-1010, Vienna, Austria.*

The Society for Industrial and Applied Mathematics will hold its National Meeting at Washington, D.C., June 11–15, 1967. For information, write *General Chairman, 1967 National Meeting, SIAM, 33 South 17th Street, Philadelphia, Pennsylvania 19103.*

The University of Massachusetts at Amherst, Massachusetts, will present a summer institute for college engineering teachers entitled "Computer Simulation of Engineering Systems." For information, write RICHARD W. TRUESWELL, *Department of Industrial Engineering, University of Massachusetts, Amherst, Massachusetts 01002.*

"The International Symposium on Automation of Population Register Systems" will be presented in September, 1967. For further information, write *International Symposium on Automation of Population Register Systems, Information Processing Association of Israel, P.O. Box 3009, Jerusalem, Israel.*

The IEEE professional group on Systems Science and Cybernetics will have its annual national meeting October 17–19, 1967, at Boston, Massachusetts. For information: FRANCIS R. COLLINS, *Mitre Corporation, Bedford, Massachusetts.*

The University of Michigan will hold a series of conferences including "Advances in the Applications of Computers to Hospital Management" (May 15–19); "Foundations and Tools for Operations Research and the Management Sciences," (May 22–June 2); "Operational Analysis in the Management of Health Services" (June 5–9); "Recent Mathematical Advances in Operations Research and the Management Sciences" (June 5–16); "Probability Theory and Random Processes for Engineers and Scientists" (July 10–21); "Topics in Military Operations Research" (July 24–August 4); and "Quality Control by Statistical Methods" (August 7–17, 1967). Write: *Engineering Summer Conferences, West Engineering Building, The University of Michigan, Ann Arbor, Michigan 48104.*

M.I.T. will hold three summer programs in Marketing, including "Computer Simulation of Market and Competitor Response" (June 13–23); "Management

Science in Marketing" (August 21-September 1); and "Marketing Information Systems" (August 21–September 1). For further information, write *Director of the Summer Session, E19-356, M.I.T., Cambridge, Massachusetts 02139.*

## COST EFFECTIVENESS ESSAY CONTEST

The Cost Effectiveness Section of ORSA has announced the Second Annual Cost Effectiveness Essay Contest. The topic this year will be *Methodology for Measurement of Effectiveness.* Details of the contest have been circulated to Society members and will also be published in *Operations Research,* Vol. 15, No. 2, March–April, 1967. Papers must be submitted no later than Sept. 10, 1967.

## SHORTER NOTICES

Under contract with NASA, the University of Georgia has established a center for the dissemination of computer programs and computer information. Known as Computer Software Management and Information Center (COSMIC), the center will make available to non-aerospace users programs developed by NASA. To be added to the mailing list, write *COSMIC, Computation Center, University of Georgia, Athens, Georgia 30601.*

The Division of Mathematical Sciences, National Academy of Sciences—National Research Council, calls attention each year to a variety of fellowships and other support for research in the mathematical sciences at both the predoctoral and postdoctoral levels. Copies of the complete current announcement are available from the *Division of Mathematical Sciences, National Academy of Sciences—National Research Council, 2101 Constitution Aveue, Washington, D.C. 20418.*

A "Directory of Present Graduate Students," with areas of specialization and career interests, is available from the *Operations Research Center, M.I.T., Room 24-215, Cambridge, Massachusetts 02139.*

Various positions in operational research are available in the U.S. Office of Education. Those interested may write DAVID S. STOLLER, *Director, Division of Operations Analysis, National Center for Educational Statistics, U.S. Office of Education, 400 Maryland Avenue, SW, Washington, D.C. 20202.*

An interdepartmental masters and doctoral program in transportation science is being offered at the University of California, Berkeley. This is sponsored by the Division of Transportation Engineering, and the Department of Industrial Engineering with the support of the Operations Research Center and the Institute of Transportation and Traffic Engineering. Students are given wide freedom to select from the extensive course offerings of the above departments for their major and from the Departments of Statistics, Mathematics, Economics, Business Administration, or City and Regional Planning for minor fields of study. Application is encouraged by students having undergraduate degrees with good records in any of the quantitative sciences. For further information or application write to the Chairman of either the *Division of Transportation Engineering* or the *Department of Industrial Engineering, University of California, Berkeley, California.*

Union College, Schenectady, New York, will initiate a new program leading to the master of science degree in Operations Research. Further information: ALFRED L. THIMM, *Bailey Hall, Union College, Schenectady, New York 12308.*

A brochure entitled "Science and the City" has been published by the Department of Housing and Urban Development. It is available from the *Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402* for 45 cents, and may be of interest to analysts concerned with various aspects of municipal planning.

The National Gaming Council will hold a Sixth Symposium on June 8–9, 1967 at the Shoreham Hotel, Washington, D.C. For further information, contact *Mrs. Joann Langston, Technical Operations/CORG, Landmark Towers, 101 Lincolnia Road, Alexandria, Virginia 22304.*

## PERSONAL ITEMS

ELLIOTT M. FOX is President of Audion Corporation, Ann Arbor Michigan.

GEORGE F. NEWELL has been appointed Research Mathematician at the Institute of Transportation and Traffic Engineering, University of California, Berkeley.

SPENCER B. SMITH is Associate Professor of Industrial Engineering, Illinois Institute of Technology, Chicago, Illinois.

PAUL O. ROBERTS is now Director of Research of the Transport Research Program, Harvard University, Cambridge, Massachusetts.

ALBERT K. HAWKES is Research Director of the Computer Sciences Division at IIT Research Institute, Chicago, Illinois.

GEORGE ADOMIAN is now David Crenshaw Barrow Professor of Mathematics, at the University of Georgia.

ALLEN V. BUTTERWORTH is head of the Mathematics Department at the General Motors Research Laboratories, Warren, Michigan.

CHIAO JEN WANG now heads the Engineering Office of the Advanced Research Projects Agency, Washington, D.C.

RICHARD S. MORSE, Senior Lecturer, Sloan School of Management has been appointed a member of the Board of Trustees of the Research Analysis Corporation, McLean, Virginia.

JAMES F. BRENNAN, representative of the Center for Naval Analyses (CNA) to the Carrier Striking Force of the Seventh Fleet from January 1965 to June 1966, has received the Navy Meritorious Public Service Citation, the Navy's second highest award to civilians outside the Navy Department, for his participation in the planning of raids by carrier aircraft on military and logistics targets in North Vietnam.

JOEL N. BLOOM is Technical Director of the Systems Science Division of the Franklin Institute Research Laboratories, Philadelphia, Pennsylvania.

ARNO CASSEL is Principal Engineer in the Operations Research Division of the Franklin Institute Research Laboratories.

ROBERT F. RINEHART has been appointed Academic Dean at the U. S. Naval Postgraduate School at Monterey, California.

PROF. A. W. SWAN is to have the degree of Doctor of Engineering honoris causa conferred upon him by the Nova Scotia Technical College.

The following have joined the staff of Operations Research Incorporated, Silver Spring, Maryland: JAKOB AUSLAENDER, ROBERT M. CLINKSCALE, JOSEPH DESKEVICH, WALTER H. ELDER, JOSEPH P. FITZMAURICE, EUGENE Q. GORDON, ROBERT

C. Jansky, Arnamdo Lago, James B. Lancaster, Jr., Evan K. Lawrence, Ronald R. Miranda, Edwin B. Parker, III, Jerome S. Plapinger, Zvi Prihar, Raymond Renola, William K. Stahlman, Delwyn A. Wilkins, Paul D. Williams, T. Leland Willis, Charles J. Wilson.

Robert James Sutherland, Chief Superintendent of the Operational Research Establishment of the Defence Research Board of Canada, and Director General of the Operational Research Division at Canadian Forces Headquarters, Ottawa, died at his desk on 4 January 1967. Well known to many members of ORSA who worked with the armed forces in Canada or the USA, he saw service with the Canadian Armoured Corps in Italy and N.W. Europe during World War II, and in Korea with the Canadian Army Operational Research Team. He obtained a Ph.D. in economics from the University of Toronto, and worked, wrote, and lectured in the fields of military strategy and international affairs. He was responsible for the integration of the various operational research sections working for the Canadian forces into a single organization, and also for the extension of their field of activity well beyond the common text book type of operational research. George Lindsey has succeeded to the position left vacant.

Henry P. Marx, meteorologist with the Environmental Science Services Administration and *ORSA Member*, died September, 18, 1966. He had been instrumental in planning, directing, and coordinating U.S. participation in the World Weather Watch—an international program of cooperation in meteorology. From September 1965 to August 1966, Mr. Marx assumed the position of chief of the Planning Unit of the World Meteorological Organization, a specialized agency of the United Nations, to assist in the development of the detailed global plan for the World Weather Watch. Before joining ESSA's Weather Bureau in January, 1964, he had been an operations analyst for Research Analysis Corporation, research scientist for The Travelers Research Center, and atmospheric physicist with the U.S. Airforce Geophysics Directorate. Born in Norristown, Pennsylvania, he attended Penn State University and received both B.Sc. and M.S. degrees in meteorology. He was a member of the American Geophysical Union and the American Meteorological Society. He is survived by his wife, the former Mildred Haring of Norristown, Pennsylvania, and four children, Stephanie, 10, Jeffrey, 8, Erika, 6, and Kent, 2.

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# Operations Research Society of America

## 1967–1968

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## OFFICERS OF THE SOCIETY

JOHN E. WALSH, *President*
System Development Corporation
2500 Colorado Avenue
Santa Monica, California 90406

JOSEPH H. ENGEL, *Vice President*
Center for Naval Analyses
1401 Wilson Boulevard
Arlington, Virginia 22209

ROBERT E. MACHOL, *Secretary*
School of Business
Northwestern University
339 Chicago Avenue
Chicago, Illinois 60611

THOMAS E. OBERBECK, *Treasurer*
Office of Research Analyses (RRRE)
Holloman AFB
New Mexico 88330

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1965–68 RALPH E. GOMORY
Thomas J. Watson Research Center
P. O. Box 218
Yorktown Heights, New York 10598

HERBERT K. WEISS
Data Systems Division
Litton Industries
8000 Woodley
Van Nuys, California 91406

1966–69 WALTER L. DEEMER
Arms Control and Disarmament Agency
Weapons Evaluation & Control
New State Department Bldg.
Washington, D. C. 20451

GEORGE E. NICHOLSON, JR.
Department of Statistics
University of North Carolina
Chapel Hill, North Carolina 27515

1967–70 ERNEST KOENIGSBERG
Matson Research Corporation
215 Market Street
San Francisco, California 94105

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501 Norton Building
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Office of Education
Washington, D. C. 20202

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## BUSINESS OFFICE

Requests for membership information and applications as well as subscriptions and orders for back issues of *Society* publications should be addressed to:

**Operations Research Society of America**
**428 East Preston Street**
**Baltimore, Maryland 21202**

# BULLETIN

OF THE

## *Operations Research Society of America*

Supplement 2 OPERATIONS RESEARCH Volume 15, 1967

# EDUCATIONAL PROGRAMS IN OPERATIONS RESEARCH

## (United States)

## 1966–67

**A Report of the Education Committee**

**OPERATIONS RESEARCH SOCIETY OF AMERICA**

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# FOREWORD

## *Introduction*

A stated objective of the ORSA Education Committee is "to collect and publish information on the programs for education in Operations Research available in educational institutions in the United States". This report is an updating and extension of an earlier report by the Committee (Bulletin, Spring 1963).

This report describes the basic elements of 27 programs concerned with operations research. These programs vary considerably in their content, degree designation, and emphasis on operations research. Inclusion of only "operations research degree programs" would have missed noting the extent to which operations research is influencing academic programs—regardless of the name of the program. Generally, the educational objective is given with each program. The term "primary operations research" has been used to designate activities and people more specifically associated with operations research than with any other discipline. Although the listing of programs is incomplete, it is extensive enough to indicate the degree to which operations research methodology and techniques have and are continuing to influence university curricula.

Because of the variability of the programs described, the Committee has declined to try to summarize or draw extensive conclusions from the program information. However, several statements do seem in order. Note first that the program descriptions indicate that it is possible for a graduate degree program in, say, industrial engineering to represent a "comprehensive" program in operations research if the student so desires. Also note that "operations research", or equivalent phrases, appear in department names in four of the 27 programs. This is a very recent development in most cases. Perhaps of greatest significance is the emergence of operations research course work at the undergraduate level and even the B.S. in Operations Research in a few instances. This is taken to be indicative of the maturization of operations research and of the recognition of operations research as a legitimate field of scientific endeavor.

## *Comments on the Program Descriptions*

Descriptions of the individual programs are listed alphabetically below. In preparing the descriptions, the Committee sought to give an *indication* of the nature of each program. To this end, each description lists the degrees offered, the faculty, the course offerings, areas of research, and statistics on enrollments and degrees granted. Additionally, each description presents a brief statement of the history and the position of the program within the college or university. The information is sufficient to impart a general understanding of the various programs and their emphasis. Further details about specific programs should be obtained directly from the schools involved. The persons to be contacted and their addresses are listed following the introductory statement.

Operations research was born in a military context and the Department of Defense continues to be an active promoter and vigorous user. Accordingly, the program descriptions include the service schools and indicate the extent to which military officers are being exposed to and/or educated in operations research.

Certain data contained in responses to the questionnaire sent out by the Committee were not used in preparing this report. Financial aid to students is generally available and was omitted from individual program descriptions. Subsequent histories of graduates were omitted as few schools reported this information. Both because of incomplete information and in the interest of keeping the descriptions to reasonable lengths, faculty educational backgrounds, publications, and research interests as well as course descriptions were omitted. Again, school catalogues should be consulted directly.

Certain schools may have been inadvertently omitted in the initial survey. Also, certain institutions did not respond. Any additions or corrections should be sent to the Committee and they will be published in a future bulletin.

If questionnaire responses were used directly, these appear in quotation. There were many areas in which judgments were necessary, for instance, in assigning degree designations and in preparing the summary of history and position. With respect to degree designations, a designation such as M.S. (O.R.) means that we judged the degree to indicate an operations research major as opposed to an M.S. (I.E.), in which case the degree was judged to indicate an I.E. major with operations research courses. The Committee, of course, assumes full responsibility for any errors and/or omissions.

*ORSA Education Committee*
CHARLES D. FLAGLE
WILLIAM S. JEWELL
JOHN D. C. LITTLE
STEPHEN M. POLLOCK
DAVID A. SCHRADY
GIFFORD H. SYMONDS
JACK R. BORSTING (CHAIRMAN)

# LISTING OF INSTITUTIONS

## The American University

*Washington, D.C. 20006*

The operations research program is offered by the Center for Technology and Administration. The center has been in operation for three years. The operations research program is designed to serve the needs of the Washington metropolitan area. It is a program for operations research in management. The Center for Technology and Administration is a joint instrumentality of the School of Business Administration and the School of Government and Public Administration. Students seeking graduate degrees in business or in government can elect comprehensive fields in the Center for Technology and Administration, one field being operations research.

*Inquiries:* Dr. Alan D. Morris, Center for Technology and Administration, The American University, 2000 G Street, N.W., Washington, D.C 20006.

### *DEGREES OFFERED*

M.A. in Government and Public Administration
M.B.A.
Ph.D. in Government and Public Administration, or Business

### *FACULTY*

*Primary Operations Research*

FULL TIME

A. D. Morris

PART TIME

M. Binkin
W. Dorfman
H. E. Fassberg
S. Gass
R. Herrmann
E. A. Johnson
S. G. Kneale
E. M. McCormick
A. G. Merten
D. E. VanTijn
T. Wang
K. O. Yung

### *COURSE OFFERINGS*

*Primary Operations Research*

55.540, Operations Research in Management
55.542, Probability and Statistics for Management Decisions
55.641, Methods of Operations Research I
55.642, Methods of Operations Research II

55.745, Seminar in Operations Research
55.411, Introduction to Management Mathematics
55.544, Advanced Management Mathematics
41.518, Linear Programming
41.519, Non-linear and Dynamic Programming

## Arizona State University

*Tempe, Arizona 85281*

"Engineering at Arizona State University was formally initiated in 1956. Operations research was assigned as the responsibility of the Industrial Engineering Department at that time and has remained the responsibility of this department."

*Inquiries:* Dr. C. B. Gambrell, Chairman, Department of Industrial Engineering, Arizona State University, Tempe, Arizona 85281.

### *DEGREES OFFERED*

B.S. in Industrial Engineering (Operations Research option)
M.S. in Engineering
M.S. in Operations Research (Industrial Engineering Department)
Ph.D. in Industrial Engineering

### *FACULTY*

*Primary Operations Research*

W. L. Lewis
A. A. B. Pritsker
R. L. Smith
O. B. Moan

*Associated with Operations Research*

INDUSTRIAL ENGINEERING

D. D. Bedworth
C. B. Gambrell
C. D. Hoyt
J. P. Decker

MATHEMATICS

E. Nering
A. Sinkov

ELECTRICAL ENGINEERING

G. Adams
J. Spragins
J. Staudhammer

### *COURSE OFFERINGS*

*Primary Operations Research*

INDUSTRIAL ENGINEERING

471g, Engineering Statistics
472g, Engineering Statistics

475g, Operations Research I
476g, Operations Research II
477g, Systems Simulation
500, Research Methods
511, Analysis of Decision Processes
533, Project Engineering
572, Engineering Statistics
573, Reliability Models
574, Mathematical Programming
575, Topics in Operation Research
576, Queueing Theory
577, Systems Analysis
578, Inventory Theory
579, Forecasting and Scheduling

*Associated with Operations Research*

MATHEMATICS

520, Stochastic Processes
521, Stochastic Processes
464, Numerical Analysis
465g, Numerical Analysis

INDUSTRIAL ENGINEERING

421g, Human Engineering
521, Human Engineering
480, Biomechanics
481g, Biomechanics
431g, Engineering Administration
531g, Engineering Administration
463g, Process Control
563, Process Control
375, Computer Programming
566, Computer Science

ELECTRICAL ENGINEERING

524, Programming Systems, Software Development
526, Programming Systems, Software Development
529, Programming Systems, Software Development
555, Applied Decision Theory, Information Theory
566, Applied Decision Theory, Information Theory
567, Applied Decision Theory, Information Theory
568, Optimal Control
588, Automata
589, Artificial Intelligence

### *RECENT AREAS OF RESEARCH*

Decision Theory
Reliability
Queueing
Graphical Methods

### *ENROLLMENT AND GRADUATION STATISTICS*

*Enrollment*

| | *1966–67* |
|---|---|
| B.S. in Engineering | 101 |
| M.S. in Engineering | 80 |
| Ph.D. | 16 |

*Total Industrial Engineering Degrees Granted*

| | *1961* | *1962* | *1963* | *1964* | *1965* | *1966** |
|---|---|---|---|---|---|---|
| B.S. in Engineering | 8 | 6 | 8 | 23 | 23 | 30 |
| M.S. in Engineering | 1 | 3 | 5 | 12 | 15 | 22 |
| Ph.D. | 0 | 0 | 0 | 1 | 0 | 6 |

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* Estimated.

## Carnegie Institute of Technology

*Pittsburgh, Pennsylvania 15213*

Operations research is a major area of emphasis in both the doctoral and master's program of the Graduate School of Industrial Administration. The Graduate School of Industrial Administration and the Department of Psychology offer interdepartmental programs in statistics and systems and communication sciences.

*Inquiries:* Dr. R. M. Cyert, Director of Admissions, Graduate School of Industrial Administration, Carnegie Institute of Technology, Pittsburgh, Pennsylvania 15213.

### *DEGREES OFFERED*

B.S. in Administration and Management Science
M.S. in Industrial Administration
Ph.D. in Industrial Administration
Ph.D. in Economics

### *FACULTY*

*Primary Operations Research*

J. Bossons
K. J. Cohen
W. W. Cooper
O. A. Davis
M. H. DeGroot
P. Frost
D. P. Gaver
H. Hinich
M. I. Kamien

C. Kriebel
R. Lucas
A. Newell
N. Schwartz
H. A. Simon
A. Stedry
G. L. Thompson
M. Thomson

*Associated with Operations Research*

H. I. Ansoff
R. G. Brandenburg
N. C. Churchill
R. M. Cyert
R. J. Duffin
J. U. Farley
B. F. Green, Jr.
L. W. Gregg
A. A. Kuehn
K. R. MacCrimmon
K. D. Mackenzie
A. J. Perlis

## *COURSE OFFERINGS*

*Primary Operations Research*

Quantitative Controls in Business I and II
Mathematical Foundations for Management Science I
Mathematical Foundations for Management Science II
Introduction to Management Analysis and Policy
Optimization Techniques
Selected Topics in Mathematical Economics
Mathematical Social Science
Complex Information Processing Systems
Business Controls and Information Systems
Advanced Production Analysis
Marketing Research
Problems in Financial Analysis
Advanced Applied Statistics I and II
Operations Research
Advanced Operations Research Seminar
Electronic Data Processing
Decision Theory
Topics in Probability Theory with Applications
Topics in Applied Statistics
Engineering Psychology

*Associated with Operations Research*

The Departments of Psychology and the College of Engineering and Science offer relevant courses in such fields as follows:

Cognitive Processes
Advanced Mathematics and Statistics
Feedback Control Systems
Information Theory

Within the Graduate School of Industrial Administration, students may take courses in such areas as listed below:

Production
Marketing

Finance
Research and Development Management
Strategy Planning and Implementation
The Management Game
Organizational Behavior
Seminar in Organizations
Social Diffusion Processes
Behavioral Theory of the Firm
Social Structure and Institutions
Microeconomics
Economic Growth and Fluctuations
Experimental Economics
Mathematical Economics
Econometrics
Advanced Economic Analysis
Equilibrating Processes

## *RECENT AREAS OF RESEARCH*

Management control and coordination
Strategic management decision making
Planning under conditions of certainty
Planning under risk and uncertainty
Critical path scheduling
Applications of heuristic programming techniques to finance
Production and marketing problems
Mathematical programming
Distinctive problems of managing industrial research and development
The design and utilization of complex simulations as learning environments
The study of the actual process of decision making in complex organizations
Computer simulations for investigating price, advertising, and product behavior in the cigarette industry
Commercial bank behavior
Consumer brand shifting and product preference behavior
Mathematical models of multiple process management operating systems
Decision rules for real time control
Impact of information systems technology on human decision making
Information systems and organization structure
Information economics in large scale electronic data processing systems
Design of programmed decision and information systems
Systems approaches to cost-effectiveness models
Auditing (accounting and managerial)
Manpower planning

Scheduling complex projects
Organization design and analysis

### *ENROLLMENT AND GRADUATION STATISTICS*

*Degrees Granted*

| | *1961* | *1962* | *1963* | *1964* | *1965* |
|---|---|---|---|---|---|
| M.S. in Industrial Administration | 48 | 48 | 44 | 57 | 58 |
| Ph.D. in Industrial Administration | 19 | 24 | 14 | 18 | 23 |

In the 1965–66 academic year, there were 53 full-time Ph.D. students in residence, 22 of which were studying operations research as a major area of concentration in their doctoral programs.

*Primary Operations Research Degrees Awarded*

| | *1957* | *1958* | *1959* | *1960* | *1961* | *1962* | *1963* | *1964* | *1965* | *1966* |
|---|---|---|---|---|---|---|---|---|---|---|
| Ph.D. | 1 | 2 | 3 | 1 | 1 | 4 | 6 | 1 | 4 | * |

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* Incomplete statistics.

## Case Institute of Technology

*Cleveland, Ohio 44106*

The Operations Research Group, Case Institute of Technology, was the first academically based operations research activity, having been founded in 1951. The first Ph.D. degrees were awarded in 1955, and M.S. degrees were first awarded in 1957. Operations Research is included in educational programs of the Division of Organizational Sciences and is the responsibility of the Operations Research Group.

*Inquiries:* Professor Burton V. Dean, Chairman, Operations Research Group, Division of Organizational Sciences, Case Institute of Technology, University Circle, Cleveland, Ohio 44106.

### *DEGREES OFFERED*

B.S. in Management Science (Operations Research option)
M.S. in Operations Research
Ph.D. (Operations Research)

### *FACULTY*

*Primary Operations Research*

S. P. Cooke
B. V. Dean
R. Evans

D. Gerwin
N. K. Jaiswal
Y. Kuratani

L. Lasdon
W. P. Pierskalla
D. Teichroew

## *Associated with Operations Research*

### ECONOMICS

B. Gold
J. Hadar
S. J. Mantel, Jr.
S. Y. Park
W. S. Peirce
G. Rosegger
M. Scriven

### BEHAVIORAL SCIENCE

F. Cliffe
S. L. Fink
G. Haberstroh
J. Handlon
N. Margulies
H. H. Medow
V. C. Michelson
M. Miles
H. A. Shepard
E. Uyeki

### MATHEMATICS

R. A. Clark
Z. Govin darajulu
M. Henriksen
J. R. Isbell
A. Marcus
B. Rankin
L. Tacaks

### ENGINEERING

R. B. Banerji
E. E. Gose
L. Lefkowitz
M. Mesarovic
J. B. Reswick
J. D. Schoefler

## *COURSE OFFERINGS*

### *Primary Operations Research*

#### UNDERGRADUATE

Org. 173, Data Processing and Computers
Org. 174, Introduction to Linear Programming
Org. 175, Introduction to Non-Linear and Dynamic Programming
Org. 176, Introduction to Stochastic Processes
Org. 177, Markov Chains in Operations Research
Org. 178, Inventory Theory I
Org. 180, Introduction to Operations Research I
Org. 181, Introduction to Operations Research II
Org. 199, Undergraduate Seminar in Organizational Science

#### GRADUATE

Org. 236.3, Econometrics I
Org. 236.4, Econometrics II
Org. 258, Operations Research in Research and Development
Org. 281, Queueing Theory
Org. 282, Operations Research in Marketing
Org. 284.1–.9, Advanced Reading in Operations Research
Org. 285.1, Dynamic Programming
Org. 286, Markov Processes
Org. 288, Inventory Theory II

Org. 294.1, Computer Applications and Simulation Techniques
Org. 294.2, Operations Research Seminar in Behavioral Sciences
Org. 294.3, Operations Research in Urban Problems
Org. 294.4, Seminar in Information Processing I
Org. 294.7, Seminar in Information Processing II
Org. 294.8, Operations Research Seminar in Network Flow Theory
Org. 295, Methods of Operations Research
Org. 296, Problems in Operations Research
Org. 297, Theory of Games and Statistical Decision Theory
Org. 299.1, Mathematical Programming I
Org. 299.3, Mathematical Programming II

*Associated with Operations Research*

ECONOMICS

Org. 61, Economics I
Org. 63, Economics II
Org. 122, Measurments for Management
Org. 123, Managerial Accounting
Org. 150, Intermediate Economic Theory
Org. 221, Financial Management
Org. 235.1, Microeconomic Theory
Org. 235.2, Macroeconomic Theory
Org. 235.3, History of Economic Theory
Org. 236.1, Mathematical Economics
Org. 237.1, Money and Banking
Org. 237.2, Economic Fluctuations
Org. 237.3, Public Finance
Org. 238.1, Economic Organization and Public Control
Org. 239.1, Labor Economics and Industrial Relations
Org. 242.1, International Economics
Org. 243.1, Economic History
Org. 243.2, Theory of Economic Growth and Development
Org. 244.1, Economics of Business Systems

BEHAVIORAL SCIENCE

Org. 80, Psychology I
Org. 105, Psychology II
Org. 136, Organization Theory
Org. 145, Personnel Administration
Org. 197, Management Theory and Executive Leadership
Org. 205, Organizational Process
Org. 210.1, Personality Theory and Developmental Psychology
Org. 210.2, Motivation and Learning

Org. 210.3, Cognitive Processes
Org. 211.1, Interpersonal Relations and Group Dynamics
Org. 211.2, Role Theory and Organizational Theory
Org. 211.3, Social Structure and Cultural Processes
Org. 212, Behavioral Measurements
Org. 214, Seminar in Organization Structure and Processes
Org. 218, Seminar in Consultative Methods and Social Change
Org. 220, Seminar in Social Interaction
Org. 222.1, Seminar in Applications of Personality and Social Psychology
Org. 222.2, Seminar in Theory of Personality and Social Psychology
Org. 223.1–.9, Seminar in Behavioral Science Theory
Org. 224.1, Seminar in Organization Behavior Methods

### MATHEMATICS

Math. 7, Linear Algebra I
Math. 8, Linear Algebra II
Math. 171, Mathematical Statistics I
Math. 172, Mathematical Statistics II
Math, 173, Statistical Methods I
Math. 174, Statistical Methods II
Math. 177, Probability I
Math. 178, Probability II
Math. 271, Theory of Statistical Estimation
Math. 272, Theory of Testing Statistical Hypothesis
Math. 273, Linear Hypothesis and Analysis of Variance
Math. 274, Experimental Design
Math. 276, Decision Functions and Game Theory
Math. 277, Advanced Probability I
Math. 278, Advanced Probability II
Math. 297, Advanced Applied Statistics I
Math. 280, Advanced Applied Statistics II
Math. 283, Non-Parametric Statistical Inference I
Math. 284, Non-Parametric Statistical Inference II

### ENGINEERING

Eng. 121, Control Engineering I
Eng. 121.1, Introduction to Automatic Control
Eng. 122, Control Engineering II
Eng. 125, Introduction to Digital Computers
Eng. 127, Introductory Systems Engineering
Eng. 142, Transportation Engineering
Eng. 144, Introduction to City Planning I
Eng. 143, Introduction to City Planning II

Eng. 225.1, Systems Theory I
Eng. 225.2, Systems Theory II
Eng. 225.3, General Systems Theory
Eng. 226.1, Artificial Intelligence
Eng. 226.2, Information Theory
Eng. 226.3, Systems Optimization
Eng. 227, Advanced Control Theory
Eng. 227.5, Optimizing and Adaptive Control

### *RECENT AREAS OF RESEARCH*

Mathematical models for car pooling systems
Stochastic flow in networks
Business games and individual decision-making profiles
Design of prepaid dental plans
Competitive bidding
New product planning and development
Organization theory
Quantitative methods in research and development management
Numerical methods for queues with complex service rates
Networks of queues
The structure of production and processing systems
Educational systems problems
Simulation models of budgeting behavior
Priority queueing systems
Multi-level and decomposition techniques
Operations research in financial management
Capital investment policies
Extension of mathematical programming techniques to the dynamic case
Decentralized optimization of coupled systems
Adaptive control policies
Optimal depletion policies
Optimal inventory issuing policies
Chance-constrained programming
Stochastic models in the social and organizational sciences
Dynamic multi-product inventory systems
Integrated management systems
Design of management information systems

### *ENROLLMENT AND GRADUATION STATISTICS*

*Enrollment 1966–67*

| | |
|---|---|
| B.S. (Management Science) | 119 |
| Graduate | |
| Part-Time | 9 |
| Full-Time | 0 |

| | |
|---|---|
| Fellows | 15 |
| Grad Assistants | 22 |
| Postdoctoral Fellow | 2 |

*Degrees Granted*

| | *1961* | *1962* | *1963* | *1964* | *1965* | *1966* |
|---|---|---|---|---|---|---|
| B.S. (Management Science) | 180 Total | | | | | |
| M.S. (Operations Research) | 13 | 13 | 13 | 15 | 10 | 15 |
| Ph.D. (Operations Research) | 3 | 2 | 6 | 5 | 4 | 4 |

### *COMMENT*

Two undergraduate degrees are offered. A Bachelor of Science in Management requires two courses in Operations Research plus additional options. A Bachelor of Science in Organizational Science requires six courses in Operations Research if the student wishes to take the Operations Research option.

## Columbia University

*New York, New York 10027*

The first year in which formal courses carrying an operations research title were offered was in 1951. These were given under industrial engineering designations. An informal arrangement within the industrial engineering department permitted operations research majors leading to the first doctoral degree awarded in 1953. The first M.S. degree for operations research in industrial engineering was awarded in 1955.

In 1963, a distinct operations research undergraduate program was started. This program is administered by the Industrial Engineering Department. The first B.S. degrees were awarded in 1964.

In 1965, approval was obtained for independent Master of Science and Doctor of Engineering Science degrees in operations research programs administered by an interdepartmental committee which is also responsible for degree programs in mathematical methods in engineering. The first M.S. degrees were awarded in 1966.

*Inquiries:* Chairman, Committee on Mathematical Methods in Engineering and Operations Research, School of Engineering and Applied Science, Columbia University, New York, N. Y. 10027.

### *DEGREES OFFERED*

B.S. in Industrial Engineering
M.S. in Industrial Engineering
M.S. in Operations Research
Eng. Sc.D. in Industrial Engineering
Eng. Sc.D. in Operations Research

## *FACULTY*

*Primary Operations Research*

FULL TIME

C. Derman
E. Ignall
M. Klein
P. Kolesar
S. B. Littauer

PART TIME

N. Agin
W. S. Dorn
E. J. Gumbel
A. J. Hoffman

*Associated with Operations Research*

M. B. Friedman
W. T. Sanders
R. J. Schwarz
R. Skalak
S. H. Unger
J. Weiner

## *COURSE OFFERINGS*

*Primary Operations Research*

I.E. E6401, Production Control
I.E. E6404, Production Sequencing
I.E. E6502, Inventory Theory
I.E. E6605–6606, Production Planning, I, II
I.E. E6701, Statistical Quality Control
I.E. E6702, Reliability Planning and Testing
I.E. E6703–4, Forecasting
I.E. E6705–6, Studies in Operations Research
I.E. E9—, Seminars
Eng. Math. E4206, Linear Algebra
Eng. Math. E4603, Advanced Engineering Statistics
Eng. Math. E4604, Stochastic Processes (Markov Chains)
Eng. Math. E4811, Digital Computers
Eng. Math. E6300, Numerical Methods
Eng. Math. E6601, Mathematical Programming I
Eng. Math. E6602, Mathematical Programming II
Eng. Math. E8401, Graph Theory with Operations Research Applications
Eng. Math. E8602, Markovian Decision Processes
Eng. Math. E8604, Mathematical Pogramming III
Math. Stat. G4001, Mathematical Methods (Real Variables)
Math. Stat. G4002, Advanced Mathematical Methods (Measure and Integration)
Math. Stat. G4105, Probability
Math. Stat. G4106, Stochastic Processes
Math. Stat. G4107, Statistical Inference
Math. Stat. G4114, Multivariate Analysis

Math. Stat. G4116, Analysis of Variance
Math. Stat.-Soc. G4117, Games and Decisions
Math. Stat. G6219–6220, Mathematical Models in the Social Sciences
E.E. E6201, Linear Systems Theory
Math. G4161–4162, Analysis
Math. G4010, Fundamental Concepts of Mathematics
Math. G4401–4402, Numerical Analysis, I, II
Math. G4413, High Speed Computers
Math. G4588, Mathematical Operations Research
Econ. G6213–6214, Economic Analysis
Econ. G6421, Mathematical Economics
Econ. G6422, Econometrics

### *RECENT AREAS OF RESEARCH*

Statistical methods in logistics
Study of the feasibility of work staggering in Manhattan's central business district
Sequential control of dynamic systems
Optimal control of Markovian systems
Statistical theory of extreme values

### *ENROLLMENT AND GRADUATION STATISTICS*

*Enrollment*

| | *1966–67* |
|---|---|
| B.S. | 16 |
| M.S. | |
| Full-Time | 25 |
| Part-Time | 70 |
| Ph.D. | |
| Full-Time | 12 |
| Part-Time | 35 |

*Degrees Granted*

| | *1960–66* |
|---|---|
| B.S. | 9 |
| M.S. | 80 |
| Ph.D. | 4 |

## **Cornell University**

*Ithaca, New York 14850*

The program in operations research was started in the early 1950's, and study in operations research was limited to those seeking a Ph.D. with operations research being their major. The first Ph.D. degree in operations research was awarded in February 1958. Since that time, the major in operations research has been extended to the Master of Science degree as well.

At the undergraduate level, students may "major" in industrial engineering, but there is no undergraduate program in operations research identified as such.

*Inquiries:* Professor Byron W. Saunders, Director, Industrial Engineering and Operations Research, Upson Hall, Cornell University, Ithaca, New York 14850.

## *DEGREES OFFERED*

M.S. in Operations Research
M.Eng. in Industrial Engineering
Ph.D. in Operations Research

## *FACULTY*

### *Primary Operations Research*

R. E. Beckhofer
R. H. Bernhard
R. W. Conway
D. L. Inglehart
K. O. Kortanek
W. L. Maxwell
N. U. Prabhu
S. Saltzman
A. Schultz, Jr.
H. M. Taylor, III
L. I. Weiss

### *Associated with Operations Research*

#### INDUSTRIAL ENGINEERING

H. P. Goode
M. W. Sampson
B. W. Saunders

#### ELECTRICAL ENGINEERING

N. DeClans
F. Jelinek
C. W. Merriam
W. E. Meserve
C. Pottle

#### COMPUTER SCIENCE

J. Hertmanis
G. Salton

#### MATHEMATICS

R. H. Farrell
H. Kesten
J. C. Kiefer
A. Nendl
F. L. Spitzer
C. J. Stone
R. J. Walker
J. Wolfowitz

#### BUSINESS AND PUBLIC ADMINISTRATION

H. Bierman, Jr.
W. H. Hansman
A. K. McAdams
S. Smidt

#### OTHER DEPARTMENTS

H. D. Block
B. G. Jones
T. C. Liu
P. J. McCarthy
F. Rosenblatt
T. A. Ryan
B. P. Stiguen

## *COURSE OFFERINGS*

*Primary Operations Research*

9120, Systems Engineering
9522, Operations Research I
9523, Operations Research II
9524, Problems in Operations Research
9525, Flow and Scheduling in Networks
9526, Mathematical Models—Development and Application
9530, Mathematical Programming
9531, Dynamic Programming
9539, Selected Topics in Mathematical Programming
9561, Queueing Theory
9562, Inventory Theory
9460, Introduction to Probability Theory with Engineering Applications
9470, Introduction to Statistical Theory with Engineering Applications
9560, Applied Stochastic Processes
9570, Intermediate Engineering Statistics
9571, Design of Experiments
9572, Statistical Decision Theory
9573, Statistical Multiple Decision Procedures
9574, Introduction to Time Series Analysis
9579, Selected Topics in Industrial Statistics
9481, Introduction to Computer Science
9580, Digital Systems Simulation
9582, Data Processing Systems
9589, Seminar in Information Processes
9550, Cost Accounting, Analysis, and Control
9501, Engineering Administration
9502, Personnel Management
9510, Work Design and Measurement
9511, Manufacturing Engineering
9512, Statistical Methods in Quality and Reliability Control
9521, Production Planning and Control
9551, Advanced Engineering Economic Analysis
9590, Special Investigations in Industrial Engineering and Operations Research
9591, Industrial Engineering and Operations Research Graduate Seminar

*Associated with Operations Research*

411, Programming Systems and Theory I
412, Programming Systems and Theory II
421, Numerical Analysis
435, Information Organization and Retrieval

### DEPARTMENT OF MATHEMATICS

331, Linear Algebra
332, Algebra and Number Theory
411–412, Introduction to Analysis

### DEPARTMENT OF ECONOMICS

619–620, Econometrics

### DEPARTMENT OF CIVIL ENGINEERING

2517, Environmental Systems Engineering I
2518, Environmental Systems Engineering II

### DEPARTMENT OF ELECTRICAL ENGINEERING

4581, Feedback Control Systems
4582, Advanced Control Systems
4583, Analog Computation
4584, Optimization Techniques in Control Systems

## *RECENT AREAS OF RESEARCH*

Statistical multiple decision ranking procedures
Information processing and operations control systems
Multi-echelon logistics
Sequential procedures and applied stochastic processes
Extension of statistical control theory

## *ENROLLMENT AND GRADUATION STATISTICS*

### *1965–1966 Enrollment*

| | *Under-graduate* | *M.Eng. (Ind.)* | *M.S.* | *Ph.D.* |
|---|---|---|---|---|
| Candidates in Operations Research | NA | NA | 15 | 17 |
| Candidates in Probability and Statistics | NA | NA | 3 | 4 |
| Candidates in Information Processing | NA | NA | 3 | 0 |
| Candidates in Industrial Engineering | 107 | 17 | 2 | 1 |

### *Past Enrollment*

| | *1961–62* | *1962–63* | *1963–64* | *1964–65* | *1965–66* |
|---|---|---|---|---|---|
| M.S./Ph.D. | 20 | 24 | 40 | 38 | 45 |
| M.Eng. (Ind.) | 2 | 8 | 10 | 11 | 17 |
| *Graduate Degrees Granted* | | | | | |
| M.Eng. | 1 | 4 | 6 | 9 | 1 |
| M.S. | 6 | 4 | 3 | 11 | 6 |
| Ph.D. | 3 | 0 | 2 | 5 | 2 |

## Georgia Institute of Technology*

*Atlanta, Georgia 30332*

Formal work in operations research dates from the early 1950's. The basic philosophical framework has been one of engineering rather than science, with emphasis placed upon operations research as an enrichment of the field of industrial engineering rather than a specialty by itself.

*Inquiries:* R. N. Lehrer, Director, School of Industrial Engineering, Georgia Institute of Technology, Atlanta, Georgia 30332.

### *DEGREES OFFERED*

B.S.I.E.
M.S. (Operations Research option)
M.S.I.E.
Ph.D. (Industrial Engineering)

### *FACULTY*

*Primary Operations Research*

A. Abruzzi
J. Banks
D. E. Fyffe
A. F. Hankea
W. W. Hines
L. A. Johnson
J. Krol
S. Senja
B. Spradlin
H. M. Wadsworth

### *COURSE OFFERINGS*

*Primary Operations Research*

I.E. 334, Optimization Methods
I.E. 434, Introduction to Operations Research
I.E. 460, Project Management Systems Design
I.E. 634, Methods of Operations Research
I.E. 660, Control Processes
I.E. 680, Systems Theory and Application I
I.E. 681, Systems Theory and Application II
I.E. 734, Operations Research I
I.E. 735, Operations Research II
I.E. 736, Operations Research III
I.E. 755, Industrial Dynamics
I.E. 760, Simulation Techniques
I.E. 790–791, Projects in Operations Research
I.E. 780–782, Seminar in Systems Research

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* Material from "University Curricula in Operations Research", Naval Science Department, United States Naval Academy, June, 1966.

I.E. 785–787, Seminar in Operations Research
Math. 407, Linear Programming
Math. 466, Introduction to Game Theory

*Associated with Operations Research*
I.E. 639, Experimental Statistics
I.E. 649, Design of Industrial Experiments
I.E. 655, Econometric Models in Engineering Economy
I.E. 749, Advanced Industrial Statistics I
I.E. 750, Advanced Industrial Statistics II
I.E. 751, Advanced Industrial Statistics III

### *RECENT AREAS OF RESEARCH*

Design, test and evaluation of multivariate acceptance sampling procedures
Allocation procedures for system reliability requirements
Simulation of medical decisions
Hospital management systems analysis
Industrial dynamics simulation of solid waste handling systems

### *ENROLLMENT AND GRADUATION STATISTICS*

*Degrees Granted*

| | *June, 1966* |
|---|---|
| B.S. in Industrial Engineering | 190 |
| M.S. and M.S. in Industrial Engineering | 30 |
| Ph.D. | 1 |

## The Johns Hopkins University

*Baltimore, Maryland 21218*

Approval for the offering of advanced degrees with major in operations research was granted by the advisory board of the School of Engineering Science in the fall of 1954, and the strength and scope of operations research activity at Johns Hopkins has grown steadily since that time. Approximately two years ago, the Department of Industrial Engineering, which had direction of the program in operations research, changed its name to Department of Operations Research and Industrial Engineering to provide a title more descriptive of the interest of staff and students.

The Department of Operations Research and Industrial Engineering is one of five departments which presently comprise the School of Engineering Science. These departments can be described as approximately co-equal with the five divisions which comprise the various departments of the Homewood campus: Humanities, Social Sciences, Physical Sciences, Biological Sciences, Engineering Science.

*Inquiries:* Professor Robert H. Roy, Dean, School of Engineering Science, The Johns Hopkins University, Baltimore, Maryland 21218.

## *DEGREES OFFERED*

B.S. (unspecified)
M.Sc. in Operations Research and Industrial Engineering
M.Sc. in Management Science (evening program)
Ph.D. in Operations Research and Industrial Engineering

## *FACULTY*

| | | |
|---|---|---|
| M. Bellmore | E. Naddor | R. H. Roy |
| J. Butterworth | L. Nemhauser | T. Sparrow |
| J. Duncan | H. L. W. Nuttle | J. P. Young |
| C. Flagle | | |

*Associated with Operations Research*
J. Liebman

## *COURSE OFFERINGS*

In the following lists, courses bearing one and two digit numbers are intended for undergraduates; courses bearing numbers in the three hundreds are intended both for undergraduates and graduate students, and courses bearing numbers in the six hundreds are exclusively for graduate students.

*Primary Operations Research*
Operations Research I
Statistical Methods II
Elementary Inventory Systems 325
Introduction to the Theory of Statistics 321
Theory of Analysis of Variance and Regression 322
Mathematical Methods of Operations Research 323–324
Seminar 611–612
Design of Experiments 605
Analysis of Response Surfaces 606
Linear and Nonlinear Programming 609–610
Theory of Optimization 603
Dynamic Programming 614
Advanced Inventory Systems 630
Special Topics in Operations Research 637–638
Stochastic Systems 639–640
Theory of Games 632
Theories of Value and Decision 643–644
Operations Research and Managerial Economics 646
Theory and Applications of Linear Graphs 651–652

*Associated with Operations Research*

Managerial Accounting 5–6
Principles of Administrations 319–320
Elementary Statistics 19
Economic Statistics 20
Industrial Statistics and Quality Control 22
Incentives 619–620
Engineering Psychology 20.316
Engineering Psychology 20.627
Statistical Methods 20.647

Many advanced students in operations research also take courses in such departments as Statistics, Mathematics, Political Economy, Social Relations, Electrical Engineering, etc.

### *RECENT AREAS OF RESEARCH*

Applications of operations research to the field of health services
Operations research projects sponsored by the Chesapeake and Potomac Telephone Company in Maryland
Studies relating to the North-East Traffic Corridor
Operations research and systems engineering study of the university library

### *ENROLLMENT AND GRADUATION STATISTICS*

*Degrees Granted*

| | *1960–61* | *1961–62* | *1962–63* | *1963–64* | *1964–65* | *1965–66* |
|---|---|---|---|---|---|---|
| B.S. | 15 | 9 | 18 | 18 | 15 | 34 |
| M.Sc. (Day) | 4 | 2 | 1 | 7 | 5 | |
| (Evening) | 0 | 0 | 0 | 5 | 18 | 36 |
| Ph.D. | 3 | 5 | 3 | 4 | 7 | |

## Massachusetts Institute of Technology

*Cambridge, Massachusetts 02139*

Operations research education at M.I.T. is conducted at the doctoral, master's, and undergraduate levels. The focus of activity is the interdepartmental Operations Research Center, which has been actively engaged in teaching and research since its founding in 1953.

At the doctoral level, most students wishing to concentrate deeply in the field do so through the interdepartmental program in operations research, which is administered by the staff of the Operations Research Center. A substantial amount of operations research is also available within departmental programs; and many students specializing in applications to fields of engineering, science, or management elect to work mainly within their departments. In either case, students enter the Massachusetts Institute of Technology Graduate School through the academic departments, later applying for the interdepartmental program if they so desire.

For the master's degree, requirements are those specified by the student's academic department. Most departments allow programs with considerable specialization in operations research.

At the undergraduate level, the Sloan School of Management offers operations research specialization through its management science option. This program has a core of courses in probabilistic systems, mathematical programming, computers, statistics, and statistical decision theory.

*Inquiries:* Professor Alvin W. Drake, Associate Director, Operations Research Center, Room 24-215, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139.

## *DEGREES OFFERED*

Ph.D. or Sc.D. with specialization in Operations Research
Ph.D. or Sc.D. in Department of Registration
S.M. in Department of Registration
S.B. in Management (Management Science option)

## *FACULTY*

### *Primary Operations Research*

#### OPERATIONS RESEARCH CENTER STAFF

E. F. Bisbee
A. W. Drake
E. G. Frankel
G. M. Kaufman
J. D. C. Little
P. M. Morse
G. P. Wadsworth
L. S. White

### *Associated with Operations Research*

D. C. Carroll
C. A. Cornell
W. B. S. Crowston
A. Fleisher
H. A. Freeman
J. R. Galbraith
M. Greenberger
A. M. Hershdorfer
F. C. Ikle
C. D. MacRae
M. L. Manheim
D. B. Montgomery
J. F. Pierce
J. Rothenberg
J. F. Shapiro
T. B. Sheridan
R. W. Simpson

## *COURSE OFFERINGS*

### *Primary Operations Research*

15.591, Mathematical Programming I
15.592, Mathematical Programming II
18.11, Operations Research
6.536J-15.594J, Probabilistic Models in Systems Engineering and Operations Research

6.28J-15.09J, Probabilistic Systems Analysis
15.593, Stochastic Systems
15.095, Statistical Decision Theory
15.597, Bayesian Analysis Studies

*Associated with Operations Research*

DEPARTMENT OF CIVIL ENGINEERING

1.07, Principles of Uncertainty
1.141, Numerical Methods of Engineering Analysis I
1.142, Numerical Methods of Engineering Analysis II
1.143, Mathematical Optimization Techniques I
1.144, Mathematical Optimization Techniques II
1.148, Decision Theories in Engineering and Planning
1.154, Simulation Methods
1.213, Transportation Systems Analysis
1.214, Transportation Systems Design
1.251, Theory of Traffic Flow
1.252, Advanced Topics in Discrete Flow Control

DEPARTMENT OF MECHANICAL ENGINEERING

2.161, Analysis and Design of Engineering Systems I
2.162, Analysis and Design of Engineering Systems II
2.181, Advanced Topics in Man-Machine Systems
2.726, Computer-Aided Design

DEPARTMENT OF ELECTRICAL ENGINEERING

6.25T, Digital System Application
6.251, Digital Computer Programming Systems
6.252, Digital Systems Engineering
6.253T, Theoretical Models for Computation
6.255T, Discrete Systems Analysis
6.256T, Applications of Combinatorial Mathematics
6.257T, Elements, Systems, and Computation
6.539, Mathematical Theory of Computation and Symbol Manipulation
6.544J, Heuristic Programming and Artificial Intelligence
6.573, Introduction to Random Processes
6.574, Transmission of Information

DEPARTMENT OF CITY AND REGIONAL PLANNING

11.20, Models and the Metropolis
11.21, The Urban Transportation Problem
11.52, Seminar on Simulation of Large-Scale Social Systems Department of Naval Architecture and Marine Engineering
13.23, Propulsion System Reliability and Control
13.93, Decision Processes in Ship Operation and Construction

### DEPARTMENT OF ECONOMICS

14.11, Linear and Nonlinear Programming
14.151, Mathematical Approach to Economics
14.371, 14.372, Statistical Theory
14.373, Time-Dependent Probability
14.374, Design and Analysis of Scientific Experiments
14.383, Econometrics

### ALFRED P. SLOAN SCHOOL OF MANAGEMENT

15.472, Risk and Uncertainty in Financial Decision Making
15.541, Management Information Technology
15.542, Management Information Systems
15.581, Industrial Dynamics I
15.582, Industrial Dynamics II
15.598, Case Studies in Quantitative Analysis
15.712, Operations Management
15.791, Operations Planning and Control Systems
15.832, Statistical Methods and Measurements in Marketing
15.852, Marketing Models

### DEPARTMENT OF AERONAUTICS AND ASTRONAUTICS

16.362J, Special Studies in Systems Engineering
16.751J, Flight Transportation
16.752J, Flight Transportation Seminar

### DEPARTMENT OF POLITICAL SCIENCE

17.321T, Introduction to Systems Analysis for Defense
17.322T, Research Problems in Defense
17.735, Seminar in Model Building in Political Science

### DEPARTMENT OF MATHEMATICS

18.13, Numerical Analysis I
18.14, Numerical Analysis II
18.15, Methods of Applied Mathematics for Engineers
18.182, Introduction to Stochastic Processes
18.20, Linear Algebra
18.53, Theory of Probability I
18.54, Theory of Probability II
18.57, Theory of Approximation Methods

## *RECENT AREAS OF RESEARCH**

Consistency and optimality in subjective portfolio selection by committee
Generalized multi-dimensional Poisson distributions for finite Markov chains

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* (Theses.)

Information and control for regional blood banking systems
Investigation of scheduling algorithms for computer time-sharing systems
Markovian decision processes with uncertain transition probabilities or rewards
Mathematical methods of examination scheduling
Mathematical models for planning and competitive bidding by semiconductor manufacturers
Model for traffic flows on a two-lane two-way rural highway
Monte Carlo simulation of air traffic flow into Logan International Airport
On some aspects of integer linear programming
Operational study of the police response system
Optimal burn-in testing of repairable equipment
Optimal policies for partially observable Markov systems
Sequential search and detection
Solution of the traveling salesman problem by dynamic programming on the hypercube
Studies in search for a conscious evader
Study of efficient decision rules for uniformly scanning detection systems
Synchronization of traffic signals in a street network
Transient analysis of non-stationary queueing systems with constant service time
A class of models for adaptive experimentation and control

### *ENROLLMENT AND GRADUATION STATISTICS**

| | *Graduated* | *In Process (1966–67)* |
|---|---|---|
| Ph.D. | 32 | 12 |

* (Interdepartmental Doctoral Program only.)

## New York University*

*Bronx, New York 10453*

Operations researchers and industrial engineers are both concerned with the same productive systems. Educational programs for both professions should, therefore, have much in common. However, the operations research program should place considerably greater emphasis on sciences and scientific methodology than the industrial engineering program.

*Inquiries:* Professor Norman Barish, Chairman, Department of Industrial Engineering and Operations Research, New York University, University Heights, Bronx, New York 10453.

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* Material from "University Curricula in Operations Research", Naval Science Department, United States Naval Academy, June, 1966.

## *DEGREES OFFERED*

M.S.
Ph.D.
D. of Eng. Science

## *FACULTY*

*Primary Operations Research*

N. N. Barish
E. Bedell
S. Blumenthal
T. Cacoullos
J. Chu
A. Cohen
S. Ehrenfeld
B. Gissler
A. Haas
L. H. Herbach
E. D. Homer
J. H. K. Kao
C. Kaplan
R. Mark
M. S. Mayzner
R. Roeloffs
J. Weitz

## *COURSE OFFERINGS*

*Primary Operations Research*

### UNDERGRADUATE

Engineering Statistics I
Engineering Statistics II
Computer Methodology
Cost Fundamentals
Engineering Economics
Methods of Operations Analysis I
Methods of Operations Analysis II
Engineering Economic Analysis
Human Factors in Engineering Design
Statistical Quality Control
Managerial Economic Analysis
Operations Research Project
Undergraduate Thesis

### GRADUATE

Individual Behavior in Industry
Industrial Safety Engineering
Engineering Economic Analysis
Methods and Work Measurement
Computer Methodology
Deterministic Methods
Engineering Statistics I
Engineering Statistics II

Production Planning and Control
Inventory Models
Industrial Scheduling
Industrial Forecasting
Managerial Economic Analysis
Sampling
Systems Analysis and Design
Theory of Organization
Cost Fundamentals
Cost Systems
Statistical Quality Control
Advanced Quality Control
Advanced Computer Methodology
Linear Programming
Introduction to Operations Research
System Simulation
Nonlinear and Dynamic Programming
Application of Probability
Elements of Renewal Processes—Markov Chains—and Applications
Regression and Analysis of Variance
Introduction to Reliability and Life Testing
Advanced Reliability and Maintainability
Applications of Nonparametric Statistics
Information and Learning Processes
Special Topics
Games and Statistical Decision Theory
Optimum Seeking Methods
Queueing
Economic Planning Models
Traffic Flow Theory
Research Frontiers
Advanced Projects
Graduate Thesis

## Northwestern University

*Evanston, Illinois 60201*

Northwestern University's academic programs in operations research were initiated in 1957 with the appointment of Dr. A. Charnes to the faculty and the creation of the present Department of Industrial Engineering and Management Sciences.

*Inquiries:* Prof. Gilbert K. Krulee, Department of Industrial Engineering and Management Science, The Technological Institute, Northwestern University, Evanston, Illinois 60201.

## *DEGREES OFFERED*

M.S. in Operations Research
Ph.D. in Operations Research

## *FACULTY*

### *Primary Operations Research*

A. Ben-Israel
A. Charnes
E. Cinlar
W. F. Duhamel
A. P. Hurter
L. G. Mitten
L. W. Swanson
L. B. Willner

### *Associated with Operations Research*

#### BUSINESS

R. H. Ballou
D. P. Jacobs
B. Parl
A. R. Sovry
G. R. Whitaker

#### ECONOMICS

R. E. Beals
R. B. Heflebower
L. N. Moses
T. J. Rothenberg
R. H. Strotz

#### ENGINEERING

S. G. Bankoff
D. S. Berry
W. L. Garrison
S. L. Hakimi
G. T. Satterly
P. W. Shuldiner
W. F. Stevens

#### INDUSTRIAL ENGINEERING

G. K. Krulee
M. Radnor
G. J. Rath
A. H. Rubenstein

#### MATHEMATICS

D. G. Austin
M. Dwass
J. W. Givens
A. A. Grau
A. F. Ifram
J. Sacs
M. Shinbrot
I. Stakgold
A. Wouk

## *COURSE OFFERINGS*

### *Primary Operations Research*

#### INDUSTRIAL ENGINEERING AND MANAGEMENT SCIENCES

- Introduction to Operations Research
- Intermediate Operations Research
  - Decision Theory and Optimization Methods
  - Mathematical Programming
  - Stochastic Systems
- Stochastic Processes (Beginning, Advanced)

Mathematical Programming
Algebraic Systems (Beginning, Advanced)
Applied Statistics
Optimization Techniques
Dynamic Programming
Allocation Problems and Mathematical Economics (Beginning, Intermediate, Advanced)
System Simulation

### ENGINEERING SCIENCE

Applications of Modern Mathematical Systems
Programming Theory
Competitive Systems Analysis
Extremal Methods, Mathematical Programming, and Systems Analysis

### BUSINESS

Mathematical Methods Applied to Business Problems
Statistical Methods Applied to Business Problems
Quantitative Methods Applied to Business Problems
Operations Research Techniques
Mathematical Programming
Quantitative Methods Seminar

## *Associated with Operations Research*

### INDUSTRIAL ENGINEERING AND MANAGEMENT SCIENCES

Computers and Information Systems (Beginning, Advanced)
Organization Theory (Beginning, Intermediate, Advanced)
Systems Synthesis and Design (Beginning, Intermediate, Advanced)
Human Factors

### ENGINEERING

Process Optimization
Optimal Design of Chemical Processes
Optimal Control
Computer and Information Science Seminar
Quantitative Methods in Transportation Engineering

### MATHEMATICS*

Probability
Statistics
Stochastic Processes
Linear Algebra
Modern Algebra

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* Courses available at beginning, intermediate, and advanced levels.

Advanced Calculus
Functional Analysis
Topology
Numerical Analysis
Complex Variables
Differential Equations
Seminars

### ECONOMICS

Economic Theory
Location, Transportation, and Regional Analysis
Statistical Inference and Economic Analysis
Activity Analysis
Econometrics
Seminar in Quantitative Economics

## *RECENT AREAS OF RESEARCH*

Theory, applications, and computations of generalized inverses
Iterative methods of linear algebra
Bounds on eigenvalues
Ill-conditioned equations
Generalized Newton-Raphson methods and their applications in nonlinear analysis and optimization
The geometry of linear inequalities
Chance constrained programming
Numerical analysis
Theory of chance constrained games
Analytic models for socio-economic processes
Biomathematics and pattern recognition
Decomposition and superposition of Markov renewal processes
Approximate procedures for solving queueing systems with general inputs and service times
Theory of stochastic sequential machines
Traffic flow theory
Variable Markov processes
Factor analysis of economic indicators
Applications of operations research in quantitative marketing
Mathematical programming and capital budgeting
Project selection and model formulation in research and development management
Equipment replacement analysis
Investment and equipment scheduling models for inland waterway carriers
Interregional firm planning models under conditions of risk

Sequential decision processes and dynamic programming
Job shop scheduling programs
Optimal design and operation of complex systems
Programming in the paper industry
Planning under certainty
Multi-period inventory models
Parametric programming
Feasibility regions in parametric systems of equations

## *ENROLLMENT AND GRADUATION STATISTICS*

*Graduation Admissions*

| *1962* | *1963* | *1964* | *1965* | *1966* | *1967* |
|---|---|---|---|---|---|
| 8 | 10 | 12 | 12 | 25 | 32 |

*Degrees Granted*

| | *1961* | *1962* | *1963* | *1964* | *1965* |
|---|---|---|---|---|---|
| M.S. (Operations Research) | 7 | 3 | 4 | 9 | 5 |
| Ph.D. (Operations Research) | 4 | 1 | 2 | 2 | 9 |

## *COMMENT*

Although Northwestern University does not offer an undergraduate degree in the field of operations research, the Bachelor of Science degree awarded in the Department of Industrial Engineering and Management Sciences includes a heavy concentration in operations research. Among the required courses are probability and statistics, stochastic systems, linear algebra, optimization theory and programming, decision and value theory, computers and data processing, mathematical economics, and systems analysis and design. Current undergraduate enrollment is 116 and 92 B.S. degrees have been awarded in the past five years.

## The Ohio State University*

*Columbus, Ohio 43210*

The basic programs are administered by the Department of Industrial Engineering, but involve several other departments as well. The majority of sponsored research projects is administered through the Systems Research Group of the Industrial Engineering Department. This group was originally formed as the Operations Research Group in 1953 and operates on an interdisciplinary basis on a wide variety of systems including industrial, health, transportation, and military.

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* Material from "University Curricula in Operations Research", Naval Science Department, United States Naval Academy, June, 1966.

*Inquiries:* Dr. William T. Morris, Chairman, Graduate Committee, Department of Industrial Engineering, The Ohio State University, Columbus, Ohio 43210.

## *DEGREES OFFERED*

B.S. (Industrial Engineering)
M.S. (Industrial Engineering)
Ph.D. (Operations Research major)

## *FACULTY*

### *Primary Operations Research*

D. F. Baker
A. B. Bishop
R. A. Brown
W. C. Giffin
R. F. Miller
W. T. Morris
C. Overby
T. H. Rockwell

### *Associated with Operations Research*

#### MATHEMATICS AND STATISTICS

H. D. Colson
J. Rustagi
C. Saltzer
J. Shapiro
D. R. Whitney

#### COMPUTER SCIENCE

T. Hildebrandt
R. Reeves

#### INFORMATION SCIENCES

M. Yovits

#### ECONOMICS

D. Bodenhorn
J. Cunnyngham
W. L'Esperence
G. Nestel
R. Tybout

#### PSYCHOLOGY

G. E. Briggs
R. L. Ernst
W. C. Howell
J. C. Naylor
H. B. Pepinsky
H. J. Wherry
D. D. Wickens

## *COURSE OFFERINGS*

### *Primary Operations Research*

#### UNDERGRADUATE

* E.M. 650, Computer Programming
* I.E. 764, Linear Programming
I.E. 798c, Inventory and Production Control
I.E. 798d, Operations Research Applications of Control Theory

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* Required undergraduate courses for I.E.'s. (Note: A minimum of six 798 courses is required.)

I.E. 798e, Decision Theory
I.E. 798f, Non-linear Programming
I.E. 798g, Network-flow Systems
I.E. 798h, Queueing
I.E. 798i, Reliability
I.E. 798j, Man-Machine Systems
I.E. 798k, Management of Technical Organizations
I.E. 7xx, Mathematical Methods (number to be assigned)

*Associated with Operations Research*
* Math. 672, Mathematical Statistics I
* Math. 673, Mathematical Statistics II
* I.E. 602, Principles of Engineering Management
* I.E. 771, Human Performance Engineering
* Math. 692, Numerical Analysis
* B.O. 650, Corporation Finance
* I.E. 706, Industrial Quality Control
* I.E. 761, Engineering Economy
* I.E. 664, Human Factors
* I.E. 708, Design of Production Facilities
I.E. 798m, Environmental Factors in Man-Machine Systems
M.E. 762, Control Theory
M.E. 763, Advanced Control Theory
Psych. 623, Engineering Psychology
Psych. 637, Industrial Psychology

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* Required undergraduate courses for I.E.'s.

GRADUATE

† I.E. 842, Operations Research I (philosophy concepts, methodology)
† I.E. 843, Operations Research II (mathematical methods)
† I.E. 844, Operations Research III (data collection implementation, practical operations research project experience)
I.E. 840, Special Problems in Operations Research
I.E. 861, Special Problems in Decision Theory
I.E. 862, Advanced Decision Theory
I.E. 863, Advanced Control Systems
I.E. 866, Advanced Mathematical Programming
I.E. 871, Advanced Human Performance Engineering

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† Core Operations Research sequence.

*Associated with Operations Research*

I.E. 801, 802, 803, Graduate Seminars
I.E. 899, Interdepartmental Seminar
Math. 601, Advanced Calculus
Math. 641, Modern Algebra
Math. 665, Mathematical Logic
Math. 670, Matrices and Determinants
Math. 674, Probability Theory
Math. 694, Advanced Numerical Analysis
Math. 695, Programming for Digital Computers (Machine Language)
Math. 704, Theory of Approximation I
Math. 705, Theory of Approximation II
Math. 725, Integral Equations
Math. 731, Advanced Probability and Statistics
Math. 733, Design of Experiments
Math. 734, Statistical Inference
Math. 790, Advanced Computer Systems Programming
Math. 793, Mathematical Foundations of Automatic Systems I
Math. 794, Mathematical Foundations of Automatic Systems II
Math. 795, Mathematical Foundations of Automatic Systems III
Math. 798, Non-parametric Statistics
Math. 807, Partial Differential Equations
Psych. 608, Statistical Methods
Psych. 626, Principles of Learning
* Psych. 8xx, Advanced Engineering Psychology
* Psych. 8xx, Seminar in Engineering Psychology
Psych. 802, Seminar in Experimental Psychology
Psych. 804, Seminar in Psychological Measurement
Psych. 815, Seminars in Psychological Statistics
Psych. 825, Methodological Foundations of Experimental Psychology
E.E. 740, Logic Circuit Theory
E.E. 742, Theory and Design of Digital Computers
E.E. 827, Communication Theory I
E.E. 828, Communication Theory II
E.E. 834, Non-linear Systems
E.E. 847, Theory and Design of Feedback Control Systems
E.E. 848, Synthesis of Linear Feedback Control Systems
E.E. 801, 802, 803, Seminars in Information Systems
Econ. 745, Linear Programming and Economic Analysis
Econ. 798e, Special Studies in Econometrics

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* Numbers yet to be assigned.

Econ. 848, Seminar in Econometrics
B.O. 687, Production Organization and Management
B.O. 799f, Industrial Management
B.O. 799h, Transportation
Soc. 801, Seminar in National Security Research

### *RECENT AREAS OF RESEARCH*

No information was available pertaining to recent research areas.

### *ENROLLMENT AND GRADUATION STATISTICS*

The following represents possibly incomplete graduation statistics:

| | *1962* | *1963* | *1964* | *1965* |
|---|---|---|---|---|
| M.S.I.E. (Operations Research option) | 4 | 8 | 14 | 4 |
| Ph.D. (Operations Research major) | 1 | 1 | 4 | 4 |

## Oklahoma State University

*Stillwater, Oklahoma 74075*

Operations research occupies a strong position with students potentially able to take graduate programs almost exclusively based on operations research course work, fortified by basic selections from mathematics and statistics.

A unique feature of the operations research program has been the formulation and development of an indepartmental operations research group.

*Inquiries:* Dr. James E. Shamblin, School of Industrial Engineering and Management, Oklahoma State University, Stillwater, Oklahoma 74075.

### *DEGREES OFFERED*

M.S. in Industrial Engineering
Ph.D. in Industrial Engineering

### *FACULTY*

*Primary Operations Research*

A. Abruzzi
E. J. Ferguson
J. E. Shamblin
G. T. Stevens
M. P. Terrell
P. E. Torgersen

*Associated with Operations Research*

S. K. Adams
W. J. Bentley
E. L. Bidwell
A. M. Breipohl
J. L. Folks
R. W. Gibson
D. E. Grosvenor
P. F. Ostwald
W. W. Rambo
W. W. Thompson
O. C. Walker

## *COURSE OFFERINGS*

*Primary Operations Research*

I.E. 323, Engineering Economy
I.E. 403, Industrial Quality Control I
I.E. 443, Introduction to Operations Research
I.E. 453, Industrial and Production Control
I.E. 500, M.S. Thesis or Report
I.E. 503, Industrial Quality Control II
I.E. 512, Engineering Research Methods
I.E. 530, Industrial Engineering Problems
I.E. 552, Industrial Programming
I.E. 553, Operations Research I
I.E. 562, Project Management
I.E. 600, Ph.D. Dissertation
I.E. 610, Special Problems
I.E. 633, Queueing and Inventory Theory
I.E. 653, Operations Research II

*Associated with Operations Research*

E.E. 433, Electronic Computer Principles
E.E. 4K3, Control Systems
E.E. 593, Digital Systems
*Math. 3X3, Linear Algebra
*Math. 403, Linear Programming
*Math. 433, Digital Computers
*Math. 4D3, Dynamic Programming
Math. 4N3, Numerical Analysis
*Math. 4P3, Introduction to Probability Theory
Math. 453, Advanced Calculus
Math. 5M3, Numerical Methods in Analysis I
Math. 5N3, Numerical Methods in Analysis II
*Stat. 323, Statistical Methods for Engineers I
*Stat. 333, Statistical Methods for Engineers II
*Stat. 423, Mathematical Statistics I
*Stat. 433, Mathematical Statistics II
Stat. 503, Experimental Designs
*Stat. 510, Stochastic Processes
Stat. 513, Sample Survey Design
*AGEC 523, Production Economics
AGEC 623, Advanced Production Economics
*AGEC 633, Econometric Methods
Econ. 5B3, Managerial Economics
Acctg. 483, Advanced Cost Accounting

Mgmt. 403, Production Management
Mgmt. 463, Activity Analysis and Decision Making
*Mgmt. 523, Managerial Analysis of Operations Problems
*Mgmt. 543, Managerial Analysis of Operations Problems II

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* Courses felt to be primarily associated with operations research

## *RECENT AREAS OF RESEARCH*

Theory and concepts applicable to production control, scheduling, and sequencing
Economic feasibility of utilizing energy conversion systems in large-scale power generating systems
Statistical application of utility theory
Investigation of probabilistic means of scheduling
Simulation of a probabilistic queueing system
Reliability theory
Quality control
Production systems control
Sequencing

## *ENROLLMENT AND GRADUATION STATISTICS*

*Graduate Industrial Engineering Enrollment*

| | *1962–63* | *1963–64* | *1964–65* | *1965–66* |
|---|---|---|---|---|
| Full-Time | 16 | 22 | 28 | 32 |
| Part-Time | 8 | 8 | 11 | 12 |

*Total Industrial Engineering Degrees Granted*

| | *1960* | *1961* | *1962* | *1963* | *1964* | *1965* |
|---|---|---|---|---|---|---|
| M.S., I.E. | 11 | 22 | 16 | 30 | 35 | 35 |
| Ph.D., I.E. | 2 | 0 | 3 | 1 | 4 | 4 |

## **Purdue University**

*Lafayette, Indiana 47907*

The first courses in operations research at Purdue University were introduced in 1955 by the School of Industrial Engineering. Several departments are currently developing their own courses in which operations research concepts and methods are adapted to specialized needs and interests of different disciplines. Degree programs in operations research can be taken in the School of Industrial Engineering, and may, on occasion, be sponsored jointly by two schools or departments. Normally, a student majors in the operations research area of industrial engineering with related course work in mathematics, statistics, computer science, economics, administrative science, and other fields of engineering.

*Inquiries:* Professor Harold T. Amrine, Head, School of Industrial Engineering, Purdue University, Lafayette, Indiana 47907.

### *DEGREES OFFERED*

M.S.I.E.
M.S.
Ph.D.

### *FACULTY*

*Primary Operations Research*

R. F. Adams
H. T. Amrine
N. R. Baker
J. W. Barany
M. M. Barash
J. R. Buck
R. D. Davis
J. H. Greene
E. G. Kirkpatrick
O. D. Lascoe
F. F. Leimkuhler
R. W. McDowell
C. L. Moodie
R. Reed, Jr.
J. A. Ritchey
C. P. Smith
H. H. Young

### *COURSE OFFERINGS*

*Primary Operations Research*

Operations Research
Advanced Mathematical Programming (3 courses)
Queues
Inventory
Economic Analysis
Production Control
Scheduling Models
Systems Design
Experimental Methods
Production Management
Management of Research and Engineering
Problems in Research Management

*Associated with Operations Research*

Statistical Control I
Satistical Control II
Computer Methods
Mathematical Programming
Cost Analysis
Work Analysis
Production Control
Systems Analysis

Engineering Administration
Measure and Probability
Stochastic Processes
Linear Analysis
Mathematical Methods in Games and Programming
Random Walks and Markov Chains
Time Series and Stochastic Processes
Optimization
Mathematical Statistics
Applied Statistics (many courses)
Numerical Analysis
Automatic Control Theory
Simulation and Information Processing
Management Science
Administrative Science
Marketing
Economic Theory
Decision Theory
Econometrics

## *RECENT AREAS OF RESEARCH*

Mathematical programming
Automatic controls
Stochastic processes
Scheduling
Research management
Work physiology and human factors
Library operations
Manufacturing
Hospital design

## *ENROLLMENT AND GRADUATION STATISTICS*

As "operations research majors" cannot be distinguished from industrial engineering or other field majors, selected course enrollments are given.

| | *1961* | *1962* | *1963* | *1964* | *1965* |
|---|---|---|---|---|---|
| Mathematical Programming (M.S. level) | 41 | 50 | 55 | 49 | 82 |
| Introduction to Operations Research (M.S. level) | 31 | 33 | 55 | 44 | 55 |
| Mathematical Programming (Ph.D. level) | 5 | 7 | 16 | 9 | 3 |
| Queueing Theory (Ph.D. level) | — | 5 | 11 | 13 | 5 |

*Degrees Granted (possibly incomplete statistics)*

| | *1960* | *1961* | *1962* | *1963* | *1964* | *1965* | *1966* |
|---|---|---|---|---|---|---|---|
| M.S.I.E. | 3 | 0 | 2 | 5 | 2 | 4 | 2 |
| Ph.D. | 2 | 1 | 1 | 3 | 4 | 1 | 2 |

### *COMMENT*

Operations research degree programs are usually undertaken at graduate level; however, an honors option for the undergraduate industrial engineering curriculum makes it possible to plan a bachelor's degree program with emphasis on operations research and related subjects.

## Stanford University

*Stanford, California 94305*

In September 1962, Stanford University established an interdepartmental program in operations research, leading to a Ph.D. degree in operations research.

The program in operations research at Stanford is housed in the graduate division of the university because of the activity's interdisciplinary nature, and draws support from the Graduate School of Business, the School of Engineering, and the School of Humanities and Sciences. There is a committee in charge of the program, consisting of faculty members from the Departments of Computer Science, Economics, Engineering-Economic Systems, Industrial Engineering, Statistics, and the Graduate School of Business.

In the university's structure, the program is not a department in that its teaching budget comes from the Schools of Business, Engineering, and Humanities and Sciences.

*Inquiries:* Dr. Gerald J. Lieberman, Chairman, Operations Research Program Committee, 544 Alvarado Row, Stanford University, Stanford, California 94305.

### *DEGREES OFFERED*

Ph.D. in Operations Research

### *FACULTY*

*Primary Operations Research*

K. J. Arrow
C. P. Bonini
G. B. Dantzig
F. S. Hillier
D. A. Howard
G. J. Lieberman
A. S. Manne
A. F. Veinott, Jr.
H. M. Wagner
R. B. Wilson
P. R. Winters

*Associated with Operations Research*

A. Bavelas
H. B. Eyring
E. A. Feigenbaum
J. W. Fondahl
G. F. Franklin
Y. Ijiri
R. K. Jaedicke
M. V. Johns, Jr.
R. E. Kalman

| | | |
|---|---|---|
| W. K. Linvill | A. A. Robicheck | B. Widrow |
| W. F. Massy | H. Solomon | D. J. Wilde |

### *COURSE OFFERINGS*

*Primary Operations Research*

Models in Reliability
Network Flows
Seminar in Operations Research
Inventory and Production Control
Data Processing in Operations Research
Queueing Theory
Nonlinear Programming and Welfare Economics
Dynamic Programming
Large Scale Systems in Mathematical Programming
Seminar in Linear Programming
Seminar in Network Theory
Seminar in Combinatorial Analysis and Integer Programming
Seminar in Reliability
Seminar in Dynamic Programming
Seminar in Inventory
Linear Programming
Mathematical Programming
Management Science Workshop

*Associated with Operations Research*

"There are numerous associated courses with operations research content given at the undergraduate and graduate level in Business, Computer Science, Economics, Electrical Engineering, Engineering-Economic Systems, Industrial Engineering, and Statistics."

### *AREAS OF RECENT RESEARCH*

Linear and nonlinear programming
Mathematical programming
Probabilistic systems-decision theory
Reliability inventory-engineering statistics-military operations research
Mathematical programming-interindustry economics
Inventory theory-simulation
Simulation of systems
Queueing theory—statistical quality control-production capital budgeting
Production systems-management games

### *ENROLLMENT AND GRADUATION STATISTICS*

*Graduate Enrollment in Residence*

| *1962–63* | *1963–64* | *1964–65* | *1965–66* |
|---|---|---|---|
| 9 | 23 | 41 | 41 |

Part-time students are not admitted in the Ph.D. program in operations research

*Degrees Granted*

| | *1965* | *1966* |
|---|---|---|
| Ph.D. (Operations Research) | 5 | 2 (incomplete) |

### *COMMENT*

In addition to the interdepartmental program in operations research, the university continues to offer master's programs and doctoral programs, emphasizing operations research, in the Departments of Industrial Engineering, Statistics, and the Graduate School of Business.

## United States Air Force Academy*

*Colorado 80840*

Courses are offered in the disciplines of computer science, economics, mathematics, and political science. Coordination is effected through the academy board and the faculty council and through an informal faculty group which meets monthly. Consideration is being given to the establishment of a major in operations research and the desirability of more formal centralization of courses.

*Inquiries:* Lieutenant Colonel J. B. MacWherter, Assistant Dean, United States Air Force Academy, Colorado 80840

### *DEGREES OFFERED*

B.S. (Mathematics, Economics, or Political Science)

### *FACULTY*

Not indicated

### *COURSE OFFERINGS*

Comp. Sci. 230, Digital Computers-Humanities Applications
Comp. Sci. 240, Digital Computers-Social Science Applications
Econ. 431, Quantitative Methods
Econ. 432, Operations Analysis
Econ. 465, Introduction to Econometrics
Econ. 466, Seminar in Econometrics
Econ. 534, Seminar in Logistics Management
Econ. 536, Seminar in Management Theory and Analysis

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* Material from "University Curricula in Operations Research", Naval Science Department, United States Naval Academy, June, 1966.

Math. 342, Probability and Statistics
Math. 441, Linear Programming
Math. 442, Game Theory
Math. 546, Probability
Pol. Sci. 484, The Formulation of Military Strategy
Pol. Sci. 486, Methods of Strategic Analysis
Pol. Sci. 488, Science Technology, and Government

## United States Military Academy*

*West Point, New York 10996*

The academic curriculum is designed to provide a broad collegiate education in the arts and sciences. Therefore, the specialization, the additional education, training, and experience needed to become an expert in operations research must be acquired after graduation.

*Inquiries:* Assistant Professor of Operations Research, Department of Ordnance, United States Military Academy, West Point, New York 10996.

### *DEGREES OFFERED*

B.S.

### *FACULTY*

*Primary Operations Research*

ORDNANCE

| | |
|---|---|
| J. R. Aker | G. M. Montgomery |

*Associated with Operations Research*

EARTH, SPACE, AND GRAPHIC SCIENCES

R. H. Hammond

MATHEMATICS

| | | |
|---|---|---|
| J. V. Foley | A. Gerardo | J. R. Mackert |

SOCIAL SCIENCES

| | |
|---|---|
| J. O. Bradshaw | W. G. T. Tuttle, Jr. |

### *COURSE OFFERINGS*

*Primary Operations Research*

Math. 204, Probability Theory and Statistical Inference
E.F. 101–102, Introduction to Digital Computers

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* Material from "University Curricula in Operations Research", Naval Science Department, United States Military Academy, June, 1966.

O.E. 487, Operations Research
O.E. 385, Management Engineering
Math. 486, Numerical Analysis with Digital Computation
Math. 481, Linear Algebra and Linear Programming
E.F. 382, Computer Science Fundamentals
S.S. 482, Applied Economic Theory and Defense Economics

*Associated with Operations Research*

Math. 487, Real Variable Theory
Math. 482, Abstract Algebra
O.E. 482, Individual Ordnance Project
C.E. 484, Individual Engineering Projects
P.L. 485, Independent Behavioral Science Studies

## United States Naval Academy*

*Annapolis, Maryland 21402*

The basic philosophy is that operations research is of great value as intellectual preparation for the naval officer-to-be. We view the study of operations research as a rational approach to the solution of real-world problems, and attempt to demonstrate how the various techniques of operations research can be directed toward solving real-world problems. Since we are educating future naval officers, our emphasis is naturally directed toward the solution of military problems.

*Inquiries:* Lieutenant Commander E. W. V. Webster, Head of Operations Committee, Naval Science Department, United States Naval Academy, Annapolis, Maryland 21402.

### *DEGREES OFFERED*

B.S.

### *FACULTY*

*Primary Operations Research*

D. G. Beatty
L. H. Fisler
J. H. Foresman
C. R. Hall
C. P. Hammon
R. Hermann
J. G. Knutson
R. R. McArthur
J. E. Newton
P. G. Schenk
R. A. Schultz
L. H. Snider
P. M. Tullier
E. W. V. Webster

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* Material from "University Curricula in Operations Research", Naval Science Department, United States Naval Academy, June, 1966.

### *COURSE OFFERINGS*

*Primary Operations Research*

N315, Naval Operations Analysis I
N316, Naval Operations Analysis II
N706, War Gaming
N707, Games of Strategy
N710, Decision Theory
N808, Naval Strategy and Military Planning
N823, Methods of Operations Research
N824, Applications of Operations Research
N906, Operations Research Project
M601, Matrix Theory
M606, Probability and Statistics II
M671, Linear Programming
H844, Advanced Economics and Problems of Defense Planning

## United States Naval Postgraduate School

*Monterey, California 93940*

The U. S. Naval Postgraduate School started a graduate program in operations research in 1951, under the direction of an interdepartmental committee. The first degrees, M.S. with major in operations research, were awarded in 1953. The program in operations research has been administered by the Department of Operations Analysis since its establishment in 1961.

*Inquiries:* Dr. Jack R. Borsting, Chairman, Department of Operations Analysis, U. S. Naval Postgraduate School, Monterey, California 93940.

### *DEGREES OFFERED*

B.S. in Operations Research
M.S. in Operations Research

### *FACULTY*

*Primary Operations Research*

OPERATIONS ANALYSIS

A. F. Andrus
D. R. Barr
E. B. Barrett
J. R. Borsting
R. M. Burton
A. Carol
R. N. Forrest
H. Greenberg
G. P. Howard
C. R. Jones
H. J. Larson
G. F. Lindsay
A. W. McMasters
P. R. Milch
C. A. Peterson
S. M. Pollock
G. K. Poock
R. R. Read

| | | |
|---|---|---|
| D. A. Schrady | G. A. Tuck | W. M. Woods |
| R. H. Shudde | J. B. Tysver | P. W. Zehna |

*Associated with Operations Research*

MATHEMATICS

F. D. Faulkner

PHYSICS

W. P. Cunningham

## *COURSE OFFERINGS*

*Primary Operations Research*

REQUIRED

Introduction to Digital Computers
Introduction to Operations Research
Methods of Operations Research/Systems Analysis
Introduction to War Gaming
Search Theory
Games of Strategy
Linear Programming
Utility Theory
Queueing Theory
Introduction to Systems Analysis
Systems Analysis

ELECTIVE

Inventory Systems
Seminar in Supply Systems
Methods for Combat Development
Selected Topics in Operations Research
Advanced Projects in Operations Research
Air Warfare
Advanced War Gaming
Theory of Pattern Recognition
Econometrics
Graph Theory
Cybernetics
Dynamic Programming

*Associated with Operations Research*

REQUIRED

Basic Probability and Set Theory
Second Course in Probability
Theory and Technique in Statistics I
Theory and Technique in Statistics II
Differential Equations and Vector Analysis

Matrix Theory
Set Theory and Integration
Macro-Economics
Micro-Economics
Cost Estimating and Analysis

### ELECTIVE

Analytic Mechanics
Fundamental Acoustics
Modern Physics
Data Processing Management
Stochastic Processes I
Stochastic Processes II
Design of Experiments
Advanced Statistics
Numerical Analysis
Intermediate Micro-Economic Theory
Decision Theory
Systems Reliability and Life Testing
Differential Equations for Optimum Control

## *RECENT AREAS OF RESEARCH*

Reliability growth
System reliability confidence intervals
Optimum routing
Repairable item inventory systems
Logistics
Gaming and simulation
Counterinsurgency warfare

## *ENROLLMENT AND GRADUATION STATISTICS*

During the past six years, 280 students were admitted to either the bachelor or the master's degree programs. Current enrollment is 151 full-time students.

The following number of degrees were awarded in the calendar year indicated:

| | *1961* | *1962* | *1963* | *1964* | *1965* | *1966* |
|---|---|---|---|---|---|---|
| B.S. (Operations Research) | 6 | 5 | 5 | 15 | 8 | 18 |
| M.S. (Operations Research) | 8 | 10 | 14 | 31 | 33 | 41 |

## *COMMENTS*

Almost all the full-time students are military officers, either Navy, Marine, Army, or Air Force. The M.S. (Operations Research) program is normally two years' duration. A thesis is required for M.S. candidates.

The department is in the process of establishing a Ph.D. program.

## University of Arizona

*Tucson, Arizona 85721*

Operations research has been an integral part of the systems engineering program since its inception in 1959. The department currently teaches some 42 hours of operations research courses and directly allied subjects. Four of the faculty are concurrently engaged in or directing research in operations research problems. Operations research is regarded as playing a fundamental role in systems engineering.

*Inquiries:* Dr. A. W. Wymore, Department of Systems Engineering, University of Arizona, Tucson, Arizona 85721.

### *DEGREES OFFERED*

B.S. in Engineering Mathematics
M.S. in Systems Engineering
Ph.D. in Systems Engineering

### *FACULTY*

*Primary Operations Research*

R. Browning
L. Duckstein
J. L. Sanders
A. W. Wymore

### *COURSE OFFERINGS*

*Primary Operations Research*

240, Operations Research I
241, Operations Research II
270, Data Processing I, II
311, Organization Theory II
320, Probabilistic Systems I
321, Probabilistic Systems II
340, Queueing Theory I
341, Theory of Inventory II
344, Design Optimization I
345, Design Optimization II
370, Systems Analysis for Data Processing I, II

*Associated with Operations Research*

120, Engineering Statistics and Probability I
121, Engineering Statistics and Probability II
150, Discrete Systems I
151, Discrete Systems II
170, Unit Record Equipment I, II
172 Introduction to Programming I, II
210, Human Factors in Engineering Design I

211, Human Factors in Engineering Design II
250, Deterministic Systems I
251, Deterministic Systems II
272, Computer Organization and Programming I, II
274, Non-Numerical Application of Digital Computer I
275, Non-Numerical Application of Digital Computer II
276, Numerical Analysis I
277, Numerical Analysis II
295, Laboratory in Computer Science I
310, Organic Systems I
330, Applications of Engineering Models I
331, Applications of Engineering Models II
350, General Systems Theory I
351, General Systems Theory II
372, Advanced Digital Computer Programing I, II
386, Bio-Engineering Models II

### *RECENT AREAS OF RESEARCH*

Open pit-mine optimization
Non-linear car-following models
Control of a vehicle through a sequence of lights to minimize polution
Determination of the time lag for visual discrimination of velocity change from a moving vehicle
Simulation of a bulk cargo shipping operation
Optimal allocation of traffic in a vehicular tunnel with restricted destination capacity
Finite-state system models of traffic problems
The measurement of human value judgments
The optimal control of stochastic service systems
Decomposition in non-linear programming
Portfolio management

### *ENROLLMENT AND GRADUATION STATISTICS*

*Enrollment*

| | *1963–64* | *1964–65* | *1965–66* | **1966–67* |
|---|---|---|---|---|
| Undergraduate | NA | NA | NA | NA |
| Graduate—Full time | 7 | 16 | 24 | 42 |
| —Part time | 13 | 7 | 10 | 16 |

*Degrees Granted*

| | *1959–60* | *1960–61* | *1961–62* | *1962–63* | *1963–64* | *1964–65* |
|---|---|---|---|---|---|---|
| B.S. Engineering Mathematics | 1 | 1 | 4 | 6 | 7 | 10 |
| M.S. Systems Engineering | 0 | 0 | 0 | 3 | 1 | 4 |

| | *1959–60* | *1960–61* | *1961–62* | *1962–63* | *1963–64* | *1964–65* |
|---|---|---|---|---|---|---|
| Ph.D. Systems Engineering | 0 | 0 | 0 | 0 | 0 | 0 |

## University of California

*Berkeley, California 94720*

### School of Business Administration

The curriculum in operations research leading to advanced degrees in this field was formally initiated in 1957 in the School of Business Administration.

*Inquiries:* Professor C. West Churchman, School of Business Administration, 310 Burrows Hall, University of California, Berkeley, California. 94720.

#### *DEGREES OFFERED*

B.S. in Business Administration
M.B.A.
Ph.D. in Business Administration, Operations Research and Management Science areas

#### *FACULTY*

*Primary Operations Research*

C. W. Churchman
B. McGuire
W. Zangwill

*Associated with Operations Research*

F. E. Balderston
I. Brosch
J. Carmen
B. Contini
F. Glover
A. C. Hoggatt
J. Rogers

#### *COURSE OFFERINGS*

*Primary Operations Research*

B.A. 175, Introduction to Operations Research I
B.A. 176, Introduction to Operations Research II
B.A. 275, Seminar in Operations Research
B.A. 276, Measurement in Decision Criteria
B.A. 277, Inventory and Waiting Line Theory I
B.A. 278, Inventory and Waiting Line Theory II
B.A. 242, Production Programming

*Associated with Operations Research*

I.E. 162, Linear Programming
I.E. 163, Queueing Theory
I.E. 164, Inventory Theory
I.E. 262, Mathematical Programming

I.E. 263, Applied Stochastic Processes
I.E. 264, Inventory Theory
I.E. 265, Reliability and Quality Control
I.E. 266, Network Flows
I.E. 290A, Non-Linear Programming
I.E. 290D, Discrete Programming
I.E. 290F, Applied Dynamic Programming
Stat. 169, Dynamic Programming

## *RECENT AREAS OF RESEARCH*

Inquiring systems
Budgetary procedure for research and development
The bases of scientific choice
Input/output analyses for educational research
Heuristic programming and engineering design
NASA and the space scientists
The origin and development of new scientific fields: the case of exobiology
Implementation of change
The legal structure of a confined micro-society
Application of systems engineering to social problems
Measure spaces of economic agents
Informational efficiency of prices
Problems in game theory and in its social science applications
The evaluation of development programs in a general linear model
Theory of resource allocation planning and decentralization
Economic problems of information and organization
Microeconomic models of business cycles
Decision-making based upon distorted information
Laboratory tests of theories of human behavior in economic games
Exploration of one of two present current topics in the savings and loan associations
Analysis of decentralization in complex organizations
Arbitration models for organizations with multiple goal structures
Information transfer, feedback and the coding of communications with task-oriented groups
Sequential search problems
Time sharing systems
Econometric models for national economic planning
Costs of on-line computer memory devices
Research on the stability of certain factors in a study of capital expenditures with a group of business executives
Optimal preventive maintenance policies

Theory of economic selection processes
Non-linear programming research

*ENROLLMENT AND GRADUATION STATISTICS*

*Enrollment*

| | *1966–67* |
|---|---|
| B.S. | 10 |
| M.B.A., Ph.D. | 10 |
| Postdoctoral | 5 |

*Degrees Granted*

| | *1961–1966* |
|---|---|
| B.S. | — |
| M.B.A. | 100 |
| Ph.D. | 10 |

## College of Engineering

Starting in 1957, the Industrial Engineering Department introduced several courses in operations research. In the 1965–66 academic year, the name of the department was changed to include the words operations research in its title. Closely allied with the activities of the department is the Operations Research Center which was organized in 1961 to support faculty and students in their research efforts. A student ORSA Chapter has been active since 1963.

*Inquiries:* Dr. Robert M. Oliver, Chairman, Department of Industrial Engineering and Operations Research, College of Engineering, University of California, Berkeley, California 94720.

*DEGREES OFFERED*

B.S. in Industrial Engineering and Operations Research
M.S. in Operations Research
Ph.D. in Operations Research

*FACULTY*

*Primary Operations Research*

R. E. Barlow
S. E. Dreyfus
D. Gale
C. R. Glassey
W. S. Jewell
O. L. Mangasarian
R. M. Oliver
R. W. Shephard
R. M. Van Slyke
R. W. Wolff

*Associated with Operations Research*

DEPARTMENT OF INDUSTRIAL ENGINEERING AND OPERATIONS RESEARCH

E. R. F. W. Crossman
E. P. DeGarmo
R. C. Grassl
E. C. Keachie
J. T. Lapley, Jr.

STATISTICS

E. W. Barankin D. Blackwell

BUSINESS ADMINISTRATION

C. W. Churchman T. A. Marschak W. Zangwill

ECONOMICS

G. Debreu D. W. Jorgenson

ELECTRICAL ENGINEERING AND COMPUTER SCIENCES

C. A. Desoer A. J. Thomasian L. A. Zadeh
O. L. Mangasorian

TRANSPORTATION ENGINEERING

G. F. Newell

ECONOMICS AND STATISTICS

R. Radner

## *COURSE OFFERINGS*

*Primary Operations Research*

UNDERGRADUATE

I.E. 150, Production Systems Analysis
I.E. 154, Industrial Data Processing Systems
I.E. 160, Introduction to Operations Research
I.E. 162, Linear Programming
I.E. 164, Introduction to Inventory Theory
I.E. 167, Queueing Theory
I.E. 180, Synthesis and Design of Industrial Systems
I.E. 198, Seminars in Operations Research

GRADUATE

I.E. 220, Economic Analysis of Engineering Systems
I.E. 251, Production Systems and Facilities
I.E. 254, Process Planning and Scheduling
I.E. 262, Mathematical Programming
I.E. 263, Applied Stochastic Processes
I.E. 264, Inventory Theory
I.E. 265, Reliability and Quality Control
I.E. 266, Network Flows and Graphs
I.E. 267, Queueing Theory
I.E. 277, Man-Machine System Analysis and Design
I.E. 290A, Non-linear Programming
I.E. 290D, Integer Programming
I.E. 290E, Advanced Mathematical Programming
I.E. 290F, Applied Dynamic Programming
I.E. 290G, Statistical Theory of Reliability and Life Testing

I.E. 290M, Advanced Applied Stochastic Processes
I.E. 298, Special Topics in Reliability
Topics in Non-Linear Programming
Inference in Queueing Systems
Mathematical Models of Transportation Systems
Stochastic Programming
Special Topics in Graph Theory
Combinatorial Problems
Production Scheduling
Special Topics in Dynamic Programming
Advanced Topics in Mathematical Programming

*Associated with Operations Research*

INDUSTRIAL ENGINEERING

I.E. 240, Policy-Level Problems in Industrial Engineering
I.E. 272, Advanced Topics in Work Systems Design and Work Measurement

CIVIL ENGINEERING

254, Deterministic Models of Traffic Flow and Transportation Networks
257, Stochastic Models in Transportation
290S, Advanced Seminar in Transportation and Related Land-Use Models
290T, Advanced Seminar in Traffic Flow Theory

ELECTRICAL ENGINEERING AND COMPUTER SCIENCE

222, Techniques of Linear Systems Theory
223A,B, Linear Network Theory
228A,B, Sampled-Data Control Systems
229A,B, Non-Linear Control Systems
252, Digital Computer Systems
263, Switching and Automata Theory
265A,B, Information Theory
290K, Theory of Optimal Control
290W, Pattern Classification

MECHANICAL ENGINEERING

134A,B, Automatic Control Systems
172A, Application of Analog Computers
227, Optimal Design of Mechanical Elements
234A,B,C, Advanced Control
235, Control Systems Design
236, Control Systems Design
237, Advanced Control Laboratory

STATISTICS

134, Methods of Probability Theory

135A,B, Methods of Statistics
152, Elementary Stochastic Processes
169, Dynamic Programming
168, Game Theory
200A,B,C, Introduction to Probability and Statistics at an Advanced Level
203A,B,C, Stochastic Processes
205A,B,C, Probability Theory
210, Advanced Theory of Statistics
216A,B, Theory of Nonparametric Inference
218, Theory of Statistical Decision Functions
230A,B, Analysis of Variance
236A,B, Analysis of Discrete Observations
252, Special Stochastic Processes
257, Probability Models in Biology and Problems of Health
261, Foundations of Random Analysis
265, Markov Processes
295A, Dynamic Programming
295D, Sequential Analysis
295F, Gambling

MATHEMATICS

104A, Introductory Analysis
104B, Intermediate Analysis
105, Integration
113C, Linear Algebra
128A,B, Numerical Analysis
120B,C, Advanced Calculus for the Applied Sciences
123, Ordinary Differential Equations
185, Introduction to the Theory of Functions of a Complex Variable
202B, Function Spaces
208, Functional Analysis
223A,B,C, Differential Equations and Operator Theory for Physical Sciences
227A,B, Theory of Recursive Functions

ECONOMICS

200A,B, Fundamentals of Economic Theory
202B,C, Advanced Economic Theory
207A,B, Mathematical Economics
233, Dynamic Aggregative Economics

BUSINESS ADMINISTRATION

241, Facilities Planning and Production Control
242, Production Programming

243, Analysis for Production Management
278, Inventory and Waiting-Line Theory
291, Seminar in Organization Theory I
292, Seminar in Organization Theory II
293, Seminar in Organization Theory III

## *RECENT AREAS OF RESEARCH*

Mathematical control and design of operational systems
Studies in operations research and mathematical programming
Computer solutions of biological models
Markov renewal and linear control processes
Gas pipeline systems optimization
Fire control systems
Hospital admissions and scheduling
Integer programming and network flows
Statistical reliability
Northeast corridor project—scheduling of transportation systems
Water resources
Solid waste management
Freeway accident systems
Computer service systems
Optimal utilization of natural resources

## *ENROLLMENT AND GRADUATION STATISTICS*

*Enrollment*

| | *1960–61* | *1961–62* | *1962–63* | *1963–64* | *1964–65* | *1965–66* |
|---|---|---|---|---|---|---|
| Undergraduate in department | 47 | 41 | 52 | 63 | 53 | 59 |
| Graduate: | | | | | | |
| in operations research | NA | NA | NA | NA | NA | 71 |
| in department | 19 | 37 | 63 | 81 | 97 | 122 |
| Postdoctoral Fellows | NA | NA | NA | NA | NA | 3 |

*Degrees Granted*

| | *1960* | *1961* | *1962* | *1963* | *1964* | *1965* |
|---|---|---|---|---|---|---|
| B.S. | 24 | 17 | 19 | 16 | 23 | 29 |
| M.S.• | 5 | 4 | 15 | 30 | 26 | 26 |
| Ph.D. | 0 | 0 | 2 | 2 | 0 | 11 |

## *COMMENTS*

The Industrial Engineering and Operations Research Department has recently developed a cooperative work-study program for Ph.D. students. Students who have completed the equivalent of an M.S. degree can now find opportunities to combine industrial work in the San Francisco bay area with their educational program at the Berkeley campus.

## University of California

*Los Angeles, California 90024*

### Graduate School of Business Administration

Operations research was first offered in this business school in 1954. Since then the offerings have expanded to a substantial curriculum, with major fields of concentration in "mathematical methods of operations research" in the Master of Science in Business Administration, and Doctor of Philosophy in Business Administration programs.

*Inquiries:* Professor James R. Jackson, Chairman, Quantitative Methods Division, Department of Business Administration, GBA 6214, University of California, Los Angeles, California 90024.

#### *DEGREES OFFERED*

M.B.A.
M.S. in Business Administration
Ph.D. in Business Administration

#### *FACULTY*

*Primary Operations Research*

G. W. Brown
A. M. Goeffrion
G. W. Graves
N. H. Hakansson
J. R. Jackson
J. B. MacQueen
J. Marschak
R. T. Nelson

#### *COURSE OFFERINGS*

About twenty distinctively operations research courses are offered mostly by the Department of Business Administration and Engineering. A full line of related courses in mathematical and applied statistics and in pertinent substantive fields is also used in the programs.

#### *RECENT AREAS OF RESEARCH*

The principal related research unit is the Business School in the Western Management Science Institute (J. Marschak, Director), which encompasses projects on decision-making processes and on production systems.

#### *ENROLLMENT AND GRADUATE STATISTICS* •

*Enrollment*

| | *1966–67* |
|---|---|
| M.B.A. | 30 |
| Ph.D. | 8 |

*Degrees Granted*

| | *Total Past Degrees* |
|---|---|
| M.B.A. | 10 or 15 per annum |
| Ph.D. | 10 |

## University of Florida

*Gainesville, Florida 32601*

Development of the operations research program at the University of Florida has occurred within the boundaries of the Department of Industrial and Systems Engineering. The first baccalaureate degree in industrial engineering awarded by the University of Florida was presented in 1935. In 1963, reflecting new philosophies at the university as well as growth and expanded breadth of the field and related areas, the name of the department was changed to the Department of Industrial and Systems Engineering. While the subject matter of operations research has been covered in courses in the department since the early 1950's, a formal master's degree program in operations research has only existed since June 1963. The doctoral program in operations research was implemented in 1965 and the Bachelor of Science in systems engineering with an operations research emphasis was approved in late 1965.

*Inquiries:* Dr. R. L. Patterson, Coordinator of Graduate Studies, Department of Industrial and Systems Engineering, University of Florida, Gainesville, Florida 32601.

### *DEGREES OFFERED*

B.S. (Systems Engineering—with "Operations Research emphasis")
M.S.E. (Operations Research)
Ph.D. (Operations Research)

### *FACULTY*

*Primary Operations Research*

R. N. Braswell
J. F. Burns
J. R. Freeman
P. E. Hicks
R. S. Levenworth
J. F. Mahoney
J. H. Moreau
R. L. Patterson
C. L. Proctor
J. C. Schaake
B. D. Sivazlian
L. E. Stanfel
M. E. Thomas
L. J. Turvaille
P. E. Valisalo
F. D. Vickers
D. B. Wilcox

*Associated with Operations Research*

W. H. Chen
O. I. Elgerd
M. R. Langhan
F. P. May
L. Polopolus
J. A. Saw
R. G. Selfridge
M. Tyner

### *COURSE OFFERINGS*

*Primary Operations Research*

UNDERGRADUATE

I.S.E. 401, Matrix Methods in Systems Engineering

I.S.E. 402, Transform Methods in Systems Engineering
I.S.E. 410, Inventory Systems
I.S.E. 421, Economic Decision Models
I.S.E. 470, Operations Research I
I.S.E. 471, Operations Research II
I.S.E. 480, Stochastic Systems

GRADUATE

I.S.E. 601, Classical Optimization Theory
I.S.E. 602, Dynamic Programming
I.S.E. 603, Dynamic Optimization Theory
I.S.E. 604, Linear Programming
I.S.E. 605, Advanced Topics in Linear Programming
I.S.E. 606, Nonlinear Programming
I.S.E. 610, Inventory Theory
I.S.E. 620, Games and Gaming
I.S.E. 621, Decision Theory
I.S.E. 652, Dynamic Modeling and Simulation
I.S.E. 661, Statistical Forecasting Models
I.S.E. 670, Mathematical Methods of Operations Research I
I.S.E. 671, Mathematical Methods of Operations Research II
I.S.E. 680, Queueing Theory
I.S.E. 681, Stochastic Service Systems

*Associated with Operations Research*

I.S.E. 350, Digital Computer Programming
I.S.E. 351, Numerical Techniques
I.S.E. 357, Analog Computer Principles
I.S.E. 420, Engineering Economy
I.S.E. 432, Production Control
I.S.E. 433, Production Systems Analysis
I.S.E. 434, Facilities Planning
I.S.E. 451, Numerical Methods in Systems Engineering
I.S.E. 452, Industrial Quality Control
I.S.E. 481, Systems Design

INDUSTRIAL AND SYSTEMS ENGINEERING-GRADUATE

I.S.E. 550, Computer Programming Systems
I.S.E. 551, Digital Computer Techniques
I.S.E. 558, Hybrid Computer Techniques
I.S.E. 562, Reliability Engineering
I.S.E. 570, Operations Analysis I
I.S.E. 571, Operations Analysis II
I.S.E. 580, Systems Analysis I
I.S.E. 581, Systems Analysis II

I.S.E. 611, Industrial Dynamics I
I.S.E. 612, Industrial Dynamics II
I.S.E. 650, Theory of Programming
I.S.E. 651, Digital Simulation Techniques
I.S.E. 653, Information Systems Analysis and Design
I.S.E. 662, Reliability Theory
I.S.E. 682, Systems Analysis and Design I
I.S.E. 683, Systems Analysis and Design II

### MATHEMATICS

M.S. 535, Finite Dimensional Vector Spaces I
M.S. 536, Finite Dimensional Vector Spaces II
M.S. 541, Modern Analysis I
M.S. 542, Modern Analysis II
M.S. 543, Modern Analysis III
M.S. 561, Introduction to Topology I
M.S. 562, Introduction to Topology II
M.S. 604, Integral Transforms for Engineers and Physical Scientists
M.S. 609, Introduction to Calculus of Variations for Engineers and Physical Scientists
M.S. 614, Numerical Analysis

### STATISTICS

Stat. 521, Experimental Design in Research I
Stat. 522, Experimental Design in Research II
Stat. 525, Design and Analysis of Experiments I
Stat. 526, Design and Analysis of Experiments II
Stat. 527, Design and Analysis of Experiments III
Stat. 540, Introduction to Theoretical Statistics I
Stat. 541, Introduction to Theoretical Statistics II
Stat. 542, Introduction to Theoretical Statistics III
Stat. 620, Theory of Completely Random and Mixed Models
Stat. 621, Design of Experiments
Stat. 660, Stochastic Processes I
Stat. 661, Stochastic Processes II
Stat. 680, Time Series I
Stat. 681, Time Series II

### ECONOMICS

E.S. 661, Econometric Methods I
E.S. 662, Econometric Methods II
E.S. 665, Mathematical Economics I
E.S. 666, Mathematical Economics II

### ENGINEERING

E.E. 602, Advanced System Theory II

E.E. 641, Theory of Communication I
E.E. 642, Theory of Communication II
E.E. 645, Statistical Decision Theory
E.E. 647, Information Theory
E.E. 663, Introduction to Automata Theory—Finite State Machines
E.E. 673, Optimum Systems Control
E.E. 674, Adaptive and Optimum Systems Control
E.E. 675, Computational Techniques in Systems Control
E.S.M. 610, Analytical Techniques for Engineers and Scientists I
E.S.M. 611, Analytical Techniques for Engineers and Scientists II
E.S.M. 612, Analytical Techniques for Engineers and Scientists III
E.S.M. 613, Principles of Engineering Analysis I
E.S.M. 614, Principles of Engineering Analysis II
E.S.M. 615, Principles of Engineering Analysis III
E.S.M. 616, Principles of Engineering Analysis IV
E.S.M. 617, Principles of Engineering Analysis V
E.S.M. 618, Approximation Techniques in Engineering and Sciences I
E.S.M. 619, Approximation Techniques in Engineering and Sciences II

### *RECENT AREAS OF RESEARCH*

Operations research methods in engineering design
Application of linear methods in nonlinear decision problems
Mathematical methods for non-algorithmic solutions of optimization problems
Approximation methods in model formulation
Inventory theory in multi-commodity, multi-warehouse systems
Theory of multi-dimensional renewal processes
Incentive contract systems
Stochastic processes in environmental systems
Safety systems and accident prevention analysis in transportation
Modeling and simulation of stochastic hospital systems
Cluster analysis
Stochastic service systems
Structures for the analysis of non-Markovian queues
Quantitative criteria for and measurements of patient care
Industrial dynamics in the time domain
Corporate strategy under imperfect information
Hybrid computer applications
Information systems for hospital managerial control
Radiological safety systems
Artificial intelligence
Systems of waiting lines
Combining monetary and nonmonetary hospital decision criteria

Facilities systems and operations research
Computer assisted instruction
Reliability of dependent systems
Micro-electronic and integrated circuit process design
Quantitative methods in information systems
Operations research in water resources engineering
Restructuring optimization problems
Resource allocation and control algorithms
Theory and applications of coding
New measures of effectiveness in stochastic networks
Theory of risk propensity and personal utility
Mathematical programming
Methods of optimization which are invariant to the structure of the objective function and constraints
Free end variational problems subject to differential inequalities
Adaptive control systems
Dynamic optimization problems in games-adaptive processes

### *ENROLLMENT AND GRADUATION STATISTICS*

*1966–67 Enrollments*

| | |
|---|---|
| Undergraduate | 196 |
| Graduate | |
| Full-Time | 46 |
| Part-Time | 177 |
| Postdoctoral Students | 2 |

*Degrees Granted*

| | *1961–1966* |
|---|---|
| B.S. | 210 |
| M.S. | 97 |
| Ph.D. | 0* |

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* The statistics represent department-wide degrees granted, including non-operations research majors. Since the Ph.D. in operations research will not produce its first graduates until 1968, there is no history available.

## The University of Michigan

*Ann Arbor, Michigan 48104*

The first course in operations research was offered in the department in 1955. Since then, the program in operations research has grown primarily as an option area of the graduate offerings in the Industrial Engineering Department, with the strong support from the Departments of Mathematics and Psychology, and the School of Business Administration.

At the present time, the Department of Industrial Engineering is the fourth largest in the College of Engineering with a full-time research and academic staff of 25 people. The operations research option is the most popular in the department, with an enrollment of approximately one-half of the master's students and three-fourths of the doctoral students. In addition to the graduate offerings on the main campus, an evening master's program is offered in Flint, Michigan, with approximately one-third of the offerings in the operations research area.

*Inquiries:* Professor R. C. Wilson, Department of Industrial Engineering, College of Engineering, The University of Michigan, 231 West Engineering Building, Ann Arbor, Michigan 48104.

### *DEGREES OFFERED*

B.S. in Industrial Engineering
M.S. in Industrial Engineering
Ph.D. in Industrial Engineering (Operations Research option)

### *FACULTY*

*Primary Operations Research*

S. Bonder
H. Bradley
R. Disney
M. Flood
H. Galliher
W. Hancock
B. Herzog
R. Jelinek
R. Thrall
D. Wilson
R. Wilson

*Associated with Operations Research*

A. B. Clarke
D. E. Cleveland
W. Edwards
W. J. Horvath
E. L. Lawler
R. W. Pew
W. Spivey
W. J. Wrobleski

### *COURSE OFFERINGS*

*Primary Operations Research*

I.E. 527, Decision Theory
I.E. 533, Problems Concerning Human Factors in Engineering Systems
I.E. 541, Analysis of Inventory Systems I
I.E. 542, Analysis of Inventory Systems II
I.E. 547, Plant Flow Analysis
I.E. 549, Automatic Process Control I
I.E. 567, Linear Statistical Models I
I.E. 568, Linear Statistical Models II
I.E. 571, Queueing Systems Analysis I
I.E. 572, Optimization in General Systems
I.E. 573, Simulation
I.E. 575, Linear Programming
I.E. 576, Nonlinear Programming

I.E. 641, Production and Inventory Control II
I.E. 671, Queueing Systems Analysis II
I.E. 675, Topics in Linear Programming
I.E. 752, Replacement and Maintenance
I.E. 819, Seminar in Stochastic Programming I
I.E. 820, Seminar in Stochastic Programming II
I.E. 876, Seminar in Operations Research I
I.E. 878, Seminar in Operations Research II

*Associated with Operations Research*

MATHEMATICS

Probability
Statistics
Linear Algebra
Advanced Calculus
Numerical Analysis
Game Theory
Combinational Analysis
Graph Theory
Linear Optimization
Nonlinear Optimization

Other courses are available in Electrical Engineering (Information Theory), Communications Science, Economics (Price Theory, Econometrics), Business Administration (Statistics and Econometrics), Psychology (Human Performance and Decision Processes), and Sociology (Process of Change).

## *RECENT AREAS OF RESEARCH*

Research on manual learning curves
Prediction of environmental stress on manual operations
The process of changing hospitals due to cost saving innovations
Methodology for determining hospital staffing requirements
The University of Michigan Hospital, industrial engineering applications
Research in the mathematics of optimization
Application of operations research techniques to the management-ordnance secondary items inventory
Information center mechanization
Use of control theory in the design of inventory control systems
An experimental analysis of the nursing service
A conceptual model for changing the administration practices on patient units to facilitate nursing care
Operations research in health manpower, Public Health Service
Programmed instruction in industrial engineering education

Research on quality control as a feedback process
Highway safety systems analysis
Development of methods for assessment of military weapons systems
Research in conversational use of computers
Decomposing and recomposing stochastic networks
Feasibility study for systems analysis of hospital organization at Henry Ford Hospital

### *ENROLLMENT AND GRADUATION STATISTICS*

*Enrollment*

| | *1966-67* |
|---|---|
| B.S. | 275 (all I.E.) |
| M.S. | |
| Full-Time | 31 |
| Part-Time | 37 |
| Ph.D. | 35 |

*Degrees Granted*

| | *1961-1966* |
|---|---|
| B.S. | 284 |
| M.S. | 122 |
| Ph.D. | 17 |

## University of Pennsylvania*

*Philadelphia, Pennsylvania 19104*

A basic program centers around course work in methods, technique, and applications of operations research, active participation in advanced seminars, and research activity with the graduate group in operations research.

*Inquiries:* Dr. Richard C. Clelland, Chairman, Department of Statistics and Operations Research, Wharton School of Finance, University of Pennsylvania, Philadelphia, Pennsylvania 19104.

### *DEGREES OFFERED*

M.S. in Operations Research
Ph.D. in Operations Research

### *FACULTY*

*Primary and Associated with Operations Research*

R. L. Ackoff
A. K. Ando
J. G. Brainerd
J. T. Chu
R. C. Clelland
P. E. Green
M. Hamburg
B. Harris
L. R. Klein

---

* Material from "University Curricula in Operations Research", Naval Science Department, United States Naval Academy, June, 1966.

S. Litwin
J. F. Lubis
A. M. McDonough
D. F. Morrison
G. M. Parks
J. S. PeCani
S. S. Sengupta
R. M. Showers
R. L. Sisson
D. B. Smith
B. H. Stevens
H. S. Wief

## *COURSE OFFERINGS*

### *Primary Operations Research*

Methodology of Operations Research
Techniques of Operations Research
Computers in Operations Research
Operations Research in Production and Inventory Control
Linear Programming
Nonlinear Programming
Dynamic Programming
Stochastic Processes in Operations Research
Queueing Theory
Sequencing and Network Theory
Reliability-Replacement and Maintenance
Game-Decision and Value Theories
Design and Control of Organizations
Mathematical Foundations of Operations Research
Forecasting and Time Series Analysis
Sample Survey Methods
Non-parametric Inference
Design of Experiments and Experimental Optimization
Regression and Variance Analysis
Multivariate Analysis
Operations Research in Marketing
Operations Research in Transportation
Operations Research in Public Planning
Operations Research in Research and Development
Simulation in Operations Research
Behavioral Variables in Operations Research
Mathematical Logic as a Basis for Quantitative Analysis
Categorical Data and Topics in Time Series Analysis

## *RECENT AREAS OF RESEARCH*

An extensive research program is carried on through the Management Science Center. Specifics were not made available.

## *ENROLLMENT AND GRADUATION STATISTICS*

This department is a new one at the University of Pennsylvania, and we have not turned out any M.S./Ph.D. graduates. There are currently 78 full-time graduate students, and theses are being written in most of the areas in which we offer instruction.

## University of Southern California

*Los Angeles, California 90007*

Our operations research program here was initiated informally about ten years ago. Until fall 1966, operations analysis course work was confined to the industrial engineering curriculum in that graduate students in industrial engineering could emphasize operations research in their programs. An independent M.S. in operations research was authorized starting in February 1966 under the control of the Industrial Engineering Department. There are no formal operations research programs at the present time at either the undergraduate or Ph.D. levels.

*Inquiries:* Dr. Homer H. Grant, Chairman, Department of Industrial Engineering, School of Engineering, University of Southern California, University Park, Los Angeles, California 90007.

### *DEGREES OFFERED*

M.S. in Operations Research

### *FACULTY*

*Primary Operations Research*

R. Beckwith
G. A. Fleischer
S. Hauer
H. Laitin
H. Linstone
A. K. Mason
H. Romig

### *COURSE OFFERINGS*

*Primary Operations Research*

- I.E. 401a, Probability Theory
- I.E. 430, Introduction to Operations Research
- I.E. 482, Introduction to Computers and Programming Techniques
- I.E. 495, Statistics and Quality Control
- I.E. 515, Introduction to Systems Engineering
- I.E. 520, Mathematical Methods of Operations Research
- I.E. 521, Advanced Statistical Aspects of Engineering Reliability
- I.E. 530, Operations Research I (Linear Programming, Game Theory)
- I.E. 531, Operations Research II (Dynamic Programming, Queueing Inventory)
- I.E. 680, Modeling and Simulation

*Associated with Operations Research*

GRADUATE SCHOOL OF BUSINESS ADMINISTRATION

- G.S.B.A. 520, Logic of Decision Making

G.S.B.A. 523, Statistical Methods
G.S.B.A. 531, Financial Planning and Management
G.S.B.A. 540, Quantitative Analysis for Business Decisions
B.E.I.T. 515, Statistical Analysis
B.E.I.T. 628ab, Seminar in Applied Statistical Theory
B.E.I.T., 635, Operations Analysis
B.E.I.T. 636, Seminar in Quantitative Business Models
B.E.I.T. 641, Forecasting Business Activity
B.E.I.T. 642, Managerial Economics
F.&R.E. 512, Financial Management of the Firm
F.&R.E. 533, Capital Budgeting

### ECONOMICS

Econ. 480, Economic Fluctuations, Growth and Forecasting
Econ. 555, Urban, Regional and Resource Economics
Econ. 585, Mathematical Economics
Econ. 686, Econometrics

### PSYCHOLOGY

Psych. 463, Industrial Psychology
Psych. 496, Learning, Memory and Thinking
Psych. 630ab, Seminar in Personnel Psychology
Psych. 650, Quantitative Methods in Psychology II

### PHILOSOPHY

Phil. 451, Symbolic Logic
Phil. 480, Philosophy of Modern Science
Phil. 485ab, Philosophy of Contemporary Science
Phil. 552, Mathematical Logic
Phil. 553, Seminar in Logic

### MATHEMATICS

Math. 403, Theory of Probability and Statistics
Math. 407, Fundamental Concepts in Probability & Statistics
Math. 409L, Introduction to Computer Data Processing
Math. 410L, Introduction to Scientific Computing
Math. 425ab, Fundamental Concepts of Analysis
Math. 461, Linear Inequalities and Linear Programming
Math. 507, Theory of Probability

### ELECTRICAL ENGINEERING

E.E. 480, Systems Engineering
E.E. 482, Introduction to Control Systems
E.E. 552ab, Logical Design of Digital Computers
E.E. 564ab, Statistical Theory of Communications and Decisions
E.E. 562ab, Linear and Nonlinear Control Systems
E.E. 583, Sampled Data Systems

## *ENROLLMENT AND GRADUATION STATISTICS*

*Current Enrollment (estimated)*

| | |
|---|---|
| M.S. in Operations Research | 10 |
| M.S. in Industrial Engineering | 80 |

There are no post-doctoral fellows at present. Total graduate admissions are about 30 per year. The first Master of Science degree in operations research was granted in August, 1966; and the expected output for the near future is three per year.

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339 Chicago Avenue
Chicago, Illinois 60611

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New Mexico 88330

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1965–68 RALPH E. GOMORY
Thomas J. Watson Research Center
P. O. Box 218
Yorktown Heights, New York 10598

HERBERT K. WEISS
Data Systems Division
Litton Industries
8000 Woodley
Van Nuys, California 91406

1966–69 WALTER L. DEEMER
Arms Control and Disarmament Agency
Weapons Evaluation & Control
New State Department Bldg.
Washington, D. C. 20451

GEORGE E. NICHOLSON, JR.
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University of North Carolina
Chapel Hill, North Carolina 27515

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### *Representative to IFORS*

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35 Acorn Park
Cambridge, Massachusetts 02140

### *Representatives to the AAAS*

W. Edward Cushen
National Bureau of Standards
U. S. Department of Commerce
Washington, D. C. 20234
Ellis A. Johnson
4819 Essex Avenue
Chevy Chase, Maryland 20015

### *Representative to the Conference Board on Mathematical Sciences*

Alex M. Mood
Office of Education
Washington, D. C. 20202

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## BUSINESS OFFICE

Requests for membership information and applications as well as subscriptions and orders for back issues of *Society* publications should be addressed to:

**Operations Research Society of America**
**428 East Preston Street**
**Baltimore, Maryland 21202**

# BULLETIN

OF THE

# *Operations Research Society of America*

**Supplement 3** **OPERATIONS RESEARCH** **Volume 15, 1967**

**Program of the Thirty-Second National Meeting**

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# *THE CHICAGO MEETING*

## REGISTRATION INFORMATION

### Registration

The registration desk will be located in the Tropical Room of the Sheraton-Chicago Hotel on Tuesday, October 31 from 7:00 PM to 11:00 PM. On meeting days it will be located in the Boulevard Room Foyer and will be open:

| | |
|---|---|
| Wednesday, November 1 | 8:00 AM–5:00 PM |
| Thursday, November 2 | 8:00 AM–5:00 PM |
| Friday, November 3 | 8:00 AM–3:00 PM |

Registration fees will be as follows:

| | |
|---|---|
| Registration, ORSA Member | $15.00 |
| Registration, ORSA Nonmember | $20.00* |
| Registration, Full Time Student | $3.00 |
| Luncheon, Thursday | $5.00 |

Except for a few designated guests, and non-member invited speakers, all attendees are expected to register and pay the established fees. This includes speakers, panel members, and session chairmen. *There will be no pre-registration by mail.*

Tickets for the Thursday Luncheon must be purchased by 5:00 PM Wednesday in order to meet Hotel guarantee requirements. Attendees are urged to purchase Luncheon tickets at time of registration. There will be a no-host Mixer on Wednesday evening from 6:00 PM until 8:00 PM in the Boulevard Room located on the fifth floor. A cash bar will be open on Tuesday evening from 7:00 PM until 11:00 PM for the convenience of registrants in the Tropical Room located on the fifth floor.

### Accommodations

The Sheraton-Chicago Hotel has blocked off 250 rooms for this meeting. The daily rates for these rooms are: Single $11–21.50; Double $16–20.50; Twin $19–21.50; and Suites $25.00 up. A form for hotel reservations is enclosed.

## COMMENTS ON PROGRAM

Sessions are being held relating to applications of operations research in various fields, and to presentations of new operations research techniques. Panels and invited paper sessions will also be held by the technical sections of the society. An Invited Lecture Series on the foundations and current work in the theory and applications of decision analysis will be presented. No previous knowledge of this subject area will be assumed.

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* A non-member wishing to apply for membership when registering may have $5 of this fee credited toward his annual dues payment of $12.50.

## COPIES OF PAPERS

Requests for copies of papers, also information about the papers, should be made directly to the authors. The addresses are contained in the statement of their affiliation. Please do not contact any of the committee for the meeting, the session chairmen, or the Editor of *The Bulletin* about the papers that are presented. Panel members should also be contacted directly about their discussions.

## LENGTH OF PAPERS

Invited papers are designated with an asterisk in this program. Ordinarily, invited papers are scheduled for 25–30 minutes, with an additional 5–10 minutes for discussion. Contributed papers are scheduled for 10 minutes, with an additional 5 minutes for discussion. The program is tightly scheduled and all authors are urged to stay within their time allowance.

## DESIGNATION OF SESSIONS AND PAPERS

Abbreviations are used to identify the technical sessions and papers in these sessions. The first letter denotes day of the week, and is W, T, or F. The second denotes AM or PM, and is A or P. A number occurs next, and identifies which of the simultaneous sessions is being considered. The last number identifies the location of a paper within the session.

# 32D NATIONAL MEETING - ORSA

## EVENT SCHEDULE

| | MEETING OFFICE | REGISTRATION & MESSAGES | LECTURE SERIES | TECHNICAL SESSION-1 | TECHNICAL SESSION-2 | TECHNICAL SESSION-3 | TECHNICAL SESSION-4 | TECHNICAL SESSION-5 |
|---|---|---|---|---|---|---|---|---|
| TUESDAY NIGHT } OCT 31 | ALHAMBRA SUITE | TROPICAL<br>7 PM-11 PM | CASH BAR - 7PM-11PM, TROPICAL ROOM (5th Floor) | | | | | |
| WEDNESDAY AM } NOV 1<br>9 AM - 12 N | | 8 AM<br>BOULEVARD ROOM FOYER (5th Floor) | | WA1<br>ASSEMBLY METHODS<br>**LAKE SUPERIOR** | WA2<br>OR APPLICATIONS-I<br>**BOULEVARD** | WA3<br>TRANSPORTATION SCIENCE-I<br>**TROPICAL** | | |
| WEDNESDAY PM } NOV 1<br>2:15 - 5:15 PM | | 5 PM | WP1 DECISION ANALYSIS-I<br>**BOULEVARD**<br>1:15 - 2:15 PM | WP2<br>MILITARY APPLICATIONS-I<br>**BOULEVARD** | WP3<br>COST EFFECTIVENESS-I<br>**CRYSTAL FOYER** | WP4<br>TRANSPORTATION SCIENCE-II<br>**TROPICAL** | WP5<br>MARKETING<br>**LAKE MICHIGAN** | |
| WEDNESDAY NIGHT } NOV 1 | | | MIXER, 6 PM - 8 PM, BOULEVARD ROOM (5th Floor) | | | | | |
| THURSDAY AM } NOV 2<br>9:15 - 12 N | | 8 AM | TA1 DECISION ANALYSIS-II<br>**CRYSTAL FOYER**<br>8:15-9:15 PM | TA2<br>SPACE SCIENCE<br>**CRYSTAL FOYER** | TA3<br>COST EFFECTIVENESS-II<br>**TROPICAL** | TA4<br>APPLICATIONS IN ECONOMICS<br>**LAKE SUPERIOR** | TA5<br>HEALTH APPLICATIONS<br>**LAKE MICHIGAN** | TA6<br>OR TECHNIQUES-I<br>**CARACAS** |
| THURSDAY NOON } NOV 2 | | | LUNCHEON, 12 N - 1:45 PM, BOULEVARD ROOM (5th Floor) | | | | | |
| THURSDAY PM } NOV 2<br>2:45 - 5:30 PM | | 5 PM | TP1 DECISION ANALYSIS-III<br>**CRYSTAL FOYER**<br>1:45 - 2:45 | TP2<br>MILITARY APPLICATIONS-II<br>**CRYSTAL FOYER** | TP3<br>SIMULATION<br>**TROPICAL** | TP4<br>NETWORK FLOWS<br>**LAKE SUPERIOR** | TP5<br>DUALITY IN GAMING & PROGRAMMING<br>**LAKE MICHIGAN** | TP6<br>OR APPLICATIONS-II<br>**CARACAS** |
| FRIDAY AM } NOV 3<br>9:15 AM - 12 N | | 8 AM | FA1 DECISION ANALYSIS-IV<br>**CRYSTAL FOYER**<br>8:15 - 9:15 | FA2<br>COST EFFECTIVENESS-III<br>**TROPICAL** | FA3<br>MILITARY APPLICATIONS-III<br>**CRYSTAL FOYER** | FA4<br>NON-LINEAR & PROBABALISTIC OPTIMIZATION TECHNIQUES<br>**LAKE SUPERIOR** | FA5<br>OR APPLICATIONS-III<br>**LAKE MICHIGAN** | FA6<br>OR TECHNIQUES-II<br>**SAN JUAN** |
| FRIDAY PM } NOV 3<br>1:30 - 4:30 PM | | 3PM | | FP1<br>COST EFFECTIVENESS-IV<br>**TROPICAL** | FP2<br>MILITARY APPLICATIONS-IV<br>**CRYSTAL FOYER** | FP3<br>OR APPLICATIONS-IV<br>**SAN JUAN** | | |

ROOM LOCATIONS : (*All Rooms in Tower Section*)

ALHAMBRA SUITE
BOULEVARD
BOULEVARD FOYER
TROPICAL
SPANISH COURT
} 5TH FLOOR

CARACAS
SAN JUAN } 11TH FLOOR
LAKE SUPERIOR
LAKE MICHIGAN } 8TH FLOOR
CRYSTAL FOYER 7TH FLOOR

COFFEE WILL BE SERVED FROM
9:30 AM UNTIL 3:30 PM DAILY
NOV. 1 - NOV. 3 IN THE
SPANISH COURT - 5TH FLOOR

# SUMMARY OF EVENTS

| | WEDNESDAY, NOVEMBER 1 | AM | |
|---|---|---|---|
| WA1 | Assembly Methods | 9:00–Noon | Lake Superior |
| WA2 | OR Applications I | 9:00–Noon | Boulevard |
| WA3 | Transportation Science Section I | 9:00–11:30 | Tropical |

| | WEDNESDAY, NOVEMBER 1 | PM | |
|---|---|---|---|
| WP1 | Decision Analysis I | 1:15–2:15 | Boulevard |
| WP2 | Military Applications Section I | 2:15–5:15 | Boulevard |
| WP3 | Cost Effectiveness Section I | 2:15–5:15 | Crystal Foyer |
| WP4 | Transportation Science Section II | 2:15–5:15 | Tropical |
| WP5 | Marketing | 2:15–5:15 | Lake Michigan |

| | THURSDAY, NOVEMBER 2 | AM | |
|---|---|---|---|
| TA1 | Decision Analysis II | 8:15–9:15 | Boulevard |
| TA2 | Space Science Section | 9:15–11:30 | Crystal Foyer |
| TA3 | Cost Effectiveness Section II | 9:15–Noon | Tropical |
| TA4 | Applications in Economics | 9:15–Noon | Lake Superior |
| TA5 | Health Applications Section | 9:15–Noon | Lake Michigan |
| TA6 | OR Techniques I | 9:15–Noon | Caracas |

| | THURSDAY, NOVEMBER 2 | PM | |
|---|---|---|---|
| TP1 | Decision Analysis III | 1:45–2:45 | Crystal Foyer |
| TP2 | Military Applications Section II | 2:45–5:30 | Crystal Foyer |
| TP3 | Simulation | 2:45–5:30 | Tropical |
| TP4 | Network Flows | 2:45–5:30 | Lake Superior |
| TP5 | Duality in Ganing and Programming | 2:45–5:30 | Lake Michigan |
| TP6 | OR Applications II | 2:45–5:30 | Caracas |

| | FRIDAY, NOVEMBER 3 | AM | |
|---|---|---|---|
| FA1 | Decision Analysis IV | 8:15–9:15 | Crystal Foyer |
| FA2 | Cost Effectiveness Section III | 9:15–Noon | Tropical |
| FA3 | Military Applications Section III | 9:15–Noon | Crystal Foyer |
| FA4 | Non-linear and Probabilistic Optimization Techniques | 9:15–Noon | Lake Superior |
| FA5 | OR Applications III | 9:15–Noon | Lake Michigan |
| FA6 | OR Techniques II | 9:15–Noon | San Juan |

| | FRIDAY, NOVEMBER 3 | PM | |
|---|---|---|---|
| FP1 | Cost Effectiveness Section IV | 1:30–4:30 | Tropical |
| FP2 | Military Applications Section IV | 1:30–4:30 | Crystal Foyer |
| FP3 | OR Applications IV | 1:30–4:30 | San Juan |

## COMMITTEE FOR THE CHICAGO MEETING

| | |
|---|---|
| *Meeting Chairman:* | Thomas E. Caywood<br>*Caywood-Schiller, Associates*<br>*401 N. Michigan Ave.*<br>*Chicago, Illinois 60611* |
| *Program Committee:* | Richard H. Rose, *Chairman*<br>Walter L. Deemer<br>*Military Applications Section*<br>John W. Locke<br>*Cost-Effectiveness Section*<br>Richard Rothery<br>*Transportation Science Section* |
| *Arrangements Chairman:* | Henry L. Kohn, Jr.<br>*Caywood-Schiller, Associates*<br>*401 N. Michigan Ave.*<br>*Chicago, Illinois 60611* |
| *Registration Chairman:* | James A. Prest<br>*Armour Company*<br>*401 N. Wabash Ave.*<br>*Chicago, Illinois 60611* |
| *Publicity Chairman:* | Thomas R. Tucker<br>*EBS Consultants*<br>*135 S. La Salle St.*<br>*Chicago, Illinois* |

## SESSION CHAIRMEN

| | |
|---|---|
| **WA1** | Nick T. Thomopoulos |
| **WA2** | H. Llewellyn Merritt |
| **WA3** | Richard Rothery |
| **WP2** | James M. Dobbie |
| **WP3** | Frederick S. Pardee |
| **WP4** | Ernst G. Frankel |
| **WP5** | Spencer B. Smith |
| **TA2** | Raoul J. Freeman |
| **TA3** | Lt. Kenneth C. Klotzkin |
| **TA4** | Robert L. Graves |
| **TA5** | Charles D. Flagle |
| **TA6** | Richard Evans |
| **TP2** | Jack R. Borsting |
| **TP3** | Cosimo A. Carlucci |
| **TP4** | T. C. Hu |
| **TP5** | Kenneth O. Kortanek |
| **TP6** | Duane S. Dunlap |
| **FA2** | John W. Locke |
| **FA3** | Thomas W. George |
| **FA4** | William M. Raike and Michael Kirby |
| **FA5** | Donald H. Schiller |
| **FA6** | Irwin Boris |
| **FP1** | John W. Locke |
| **FP2** | William A. Carswell |
| **FP3** | Robert E. Machol |

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Zschau, Edwin V. W.: **WP 3.3**

# PROGRAM

### Of The

# THIRTY-SECOND NATIONAL MEETING

### Of The

# OPERATIONS RESEARCH SOCIETY OF AMERICA

**WEDNESDAY AM, NOVEMBER 1** LAKE SUPERIOR ROOM

Session WA1: 9:00 AM–Noon

## Assembly Methods

*Chairman:* NICK T. THOMOPOULOS
*IIT Research Institute, Chicago, Illinois*

**WA1.1** ***An Assembly Line Simulator,** C. L. MOODIE, *Purdue University, Purdue, Indiana.*

**WA1.2** ***A Study of the Robustness of Assembly Line Production Rates With Respect to Allocation of Work Between Stations,** R. W. BOLING, *University of Tennessee, Knoxville, Tennessee.*

**WA1.3** **A Heuristic Approach to Assembly Line Balancing,** J. L. CNOSSEN, *Ford Motor Company, Dearborn, Michigan.*

**WA1.4** ***ALPS—An Assembly Line Planning System,** N. J. BURKHARD, *General Electric Company, Schenectady, New York.*

**WA1.5** **A Heuristic Branch and Bound Technique for Line Balancing,** N. R. REEVE *and* W. H. THOMAS, *Department of Industrial Engineering, State University of New York at Buffalo, Buffalo, New York.*

**WA1.6** ***On Criteria for Assigning Models to Assembly Lines,** M. LEHMAN, *IIT Research Institute, Chicago, Illinois.*

**WA1.7** ***Stocking for An Automotive Assembly Line,** W. B. MOORE, *International Harvester Company, Chicago, Illinois.*

**WA1.8** **Sequence Dependent Set-Up Times: A Prediction Method and an Associated Technique for Sequencing Production,** C. H. WHITE, *E. I. DuPont de Nemours Co., Inc., Wilmington, Delaware.*

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* An asterisk signifies an invited paper.

**WEDNESDAY AM, NOVEMBER 1** BOULEVARD ROOM

Session WA2: 9:00 AM–Noon

## OR Applications I

*Chairman:* H. LLEWELLYN MERRITT
*Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland.*

**WA2.1** **Operations Analysis in the Mediterranean H-Bomb Search,** H. R. RICHARDSON, *Daniel H. Wagner, Associates, Paoli, Pennsylvania.*

**WA2.2** **A Reliability Based Measure of Systems Effectiveness,** M. E. CAREHART *and* J. K. HANCOCK, *Martin Marietta Corp., Denver, Colorado.*

**WA2.3** **The Fire Allocation Problem,** DANIEL O. ETTER, JR., *Institute for Defense Analyses, Arlington, Virginia.*

**WA2.4** **Optimal Attack of a Communications Network,** M. BELLMORE, H. GREENBERG *and* J. JARVIS, *Johns Hopkins University, Baltimore, Maryland.*

**WA2.5** **Life Distributions Derived from Stochastic Hazard Functions,** C. M. HARRIS, *Research Analysis Corp., McLean, Virginia, and* N. D. SINGPURWALLA, *Western Electric Co., Inc., Princeton, New Jersey.*

**WA2.6** **Warehouse Space Estimations,** B. S. GOULD, JR., *General Mills, Inc., Minneapolis, Minnesota.*

**WA2.7** **A Computer Simulation of a Linen Supply Plant.** D. ALLEN *and* J. P. KOWAL, *Dunlap and Associates, Darien, Connecticut.*

**WA2.8** **Nuclear Warfare Analysis and the Scientific Process,** STANLEY COHEN, *TRW Systems, San Bernadino, California.*

WEDNESDAY AM, NOVEMBER 1 TROPICAL ROOM

Session WA3: 9:00 AM–11:30 AM

## Transportation Science Section I

*Chairman:* RICHARD ROTHERY
*General Motors Research Laboratories, Warren, Michigan.*

WA3.1 ***Stability of a Car-Following Model with Variable Time Delay,** LUCIEN DUCKSTEIN, ESTAN F. IMLER *and* ERNEST A. UNWIN, *Systems Engineering Department, The University of Arizona, Tucson, Arizona.*

WA3.2 ***A Discrete Model of Vehicular Traffic,** MICHAEL C. DUNNE *and* RICHARD W. ROTHERY, *General Motors Research Laboratories, Warren, Michigan, and* RENFREY B. POTTS, *University of California, Berkeley, California.*

WA3.3 ***Surveillance and Control of Tunnel Traffic by an On-Line Digital Computer,** ROBERT S. FOOTE, *The Port of New York Authority, New York, and* DENOS C. GAZIS, *IBM Research Center, Yorktown Heights, New York.*

WA3.4 ***q's and Q's,** A. MAY, G. F. NEWELL, R. M. OLIVER *and* R. B. POTTS, *University of California, Berkeley, California.*

WEDNESDAY AM, NOVEMBER 1 TROPICAL ROOM

11:30 AM–Noon

## Transportation Science Section: Business Meeting

*Chairman:* RICHARD ROTHERY

WEDNESDAY PM, NOVEMBER 1 BOULEVARD ROOM

Session WP1: 1:15 PM–2:15 PM

## Decision Analysis I

RONALD A. HOWARD
*Stanford University, Stanford, California*

**WEDNESDAY PM, NOVEMBER 1** BOULEVARD ROOM

Session WP2: 2:15 PM–5:15 PM

## Military Applications Section I
## Search and Surveillance

*Chairman:* JAMES M. DOBBIE
*Arthur D. Little, Inc., Cambridge, Massachusetts*

**WP2.1** ***A Survey of Search Theory,** J. M. DOBBIE, *Arthur D. Little, Inc., Cambridge, Massachusetts.*

**WP2.2** ***Search and Information Theory,** B. O. KOOPMAN, *Columbia University, New York, New York.*

**WP2.3** ***Search, Detection and Subsequent Action: Some Problems on the Interfaces,** S. M. POLLOCK, *Naval Postgraduate School, Monterey, California.*

**WP2.4** ***Surveillance Guided Search,** G. E. KIMBALL, *Arthur D. Little, Inc., Cambridge, Massachusetts.*

**WP2.5** ***Search Games,** R. P. ISAACS, *Center for Naval Analyses, Arlington, Virginia.*

WEDNESDAY PM, NOVEMBER 1 CRYSTAL FOYER

Session WP3: 2:15 PM–5:15 PM

## Cost Effectiveness Section I Research Allocation—Potentials for Systematic Analysis

FREDERICK S. PARDEE
*The RAND Corporation, Santa Monica, California*

WP3.1 **The Problem and Its Environment,** F. S. PARDEE

WP3.2 **A Method for Linking Defense Sciences, Technologies and Missions,** MAJOR JOSEPH P. MARTINO, *Air Force Office of Aerospace Research, Arlington, Virginia.*

WP3.3 **The Contribution of Resource Allocation, Theory and Marginal Analysis,** EDWIN V. W. ZSCHAU, *Harvard University, Boston, Mass., and* HENRY B. EYRING, *Stanford University, Palo Alto, California.*

WP3.4 **A Decision Model Under Uncertainty,** NILS H. HAKANSSON, *Yale University, New Haven, Connecticut.*

WP3.5 **Query Techniques, Panels of Experts and Sociomatic Considerations,** HOWARD A. WELLS, *Bell Aerosystems Company, Buffalo, New York.*

WP3.6 **Framework for a Comprehensive Analytic Method,** CHARLES P. BONINI, *Stanford University, Palo Alto, California.*

WP3.7 **Panel Discussion—Systematic Analysis of Science: Desirability, Feasibility and Extent,** THE SPEAKERS.

WEDNESDAY PM, NOVEMBER 1 CRYSTAL FOYER

5:15 PM–6:00 PM

## Cost Effectiveness Section: Business Meeting

WEDNESDAY PM, NOVEMBER 1 TROPICAL ROOM

Session WP4: 2:15 PM–5:15 PM

## Transportation Science Section II

*Chairman:* ERNST G. FRANKEL
*Litton Industries, Culver City, California*

WP4.1 ***A Transportation Scheduling Model,** J. H. HOGAN *and* L. DUCKSTEIN, *University of Arizona, Tucson, Arizona.*

WP4.2 ***Optimization of Integrated Sea-port Operations,** A. NOVAES, *Litton Industries, Culver City, California.*

**WP4.3** ***Transportation Problem Application to Schedule Multi-commodities with Pre-determined Priorities Using Shortest Path Techniques,** M. ARBABI *and* H. M. HOROWITZ, *International Business Machines, Gaithersburg, Md.*

**WP4.4** ***Container Provisioning for an Airline Network,** M. GUREL *and* D. M. WINBIGLER, *The Boeing Company, Renton, Washington.*

**WEDNESDAY PM, NOVEMBER 1** LAKE MICHIGAN ROOM

Session WP5: 2:15 PM–5:15 PM

## Marketing

*Chairman:* SPENCER B. SMITH
*Illinois Institute of Technology, Chicago, Illinois*

**WP5.1** ***Operations Research in Marketing—A Progress Report,** PHILIP KOTLER, *Northwestern University, Evanston, Illinois.*

**WP5.2** ***Allocating Field Sales Efforts by Means of Linear Programming,** ROBERT M. OLSEN, *University of Kansas, Lawrence, Kansas.*

**WP5.3** ***Economic Production Theory in Marketing,** KRISTIAN S. PALDA, *Claremont Graduate School, Claremont, California.*

**WP5.4** ***Operations Research in Marketing,** KURT H. SCHAFFIR, *Arthur Anderson & Co., New York, New York.*

**WP5.5** ***A Model for New Product Selection,** GLEN L. URBAN, *Massachusetts Institute of Technology, Cambridge, Massachusetts.*

**WP5.6** **Simulation Analysis of Product Testing Procedures,** RALPH L. DAY, *Indiana University, Bloomington, Indiana.*

**WEDNESDAY PM, NOVEMBER 1** BOULEVARD ROOM

6:00 PM–8:00 PM

## Mixer

**THURSDAY AM, NOVEMBER 2** CRYSTAL FOYER

Session TA1: 8:15 AM–9:15 AM

## Decision Analysis II

RONALD A. HOWARD
*Stanford University, Stanford, California*

**THURSDAY AM, NOVEMBER 2** CRYSTAL FOYER

### Session TA2: 9:15 AM–11:30 AM

## Space Science Section

Panel Discussion: "Operations Research and Range Management"

*Chairman:* R. J. FREEMAN, *Manager, Special Studies Program, General Electric Center for Advanced Studies, Santa Barbara, California.*

*Panelists:* MAJOR GENERAL J. S. BLEYMAIER, *Deputy Director for Manned Orbiting Laboratory—Space Systems Division, United States Air Force, Los Angeles, California.*

E. C. BUCKLEY, *Associate Administrator for Tracking and Data Acquisition, National Aeronautics and Space Administration, Washington, D. C.*

BRIGADIER GENERAL C. J. KRONAUER, *Commander, Air Force Western Test Range, Vandenberg Air Force Base, California.*

REAR ADMIRAL R. N. SHARP, *Commander, Pacific Missile Range, Department of the Navy, Pt. Mugu, California.*

**THURSDAY AM, NOVEMBER 2** CRYSTAL FOYER

### 11:30 AM–Noon

## Space Sciences Section: Business Meeting

An organizational business meeting for the newly formed Space Sciences Section of ORSA will be held.

**THURSDAY AM, NOVEMBER 2** TROPICAL ROOM

### Session TA3: 9:15 AM–Noon

## Cost-Effectiveness Section II
## Developments in Military Cost/System Effectiveness

*Chairman:* LT. KENNETH C. KLOTZKIN
*Rome Air Development Center, Griffiss Air Force Base, New York*

**TA3.1** ***Systems/Cost Effectiveness Implementation,** JEROME KLION, *Rome Air Development Center, New York.*

**TA3.2** ***Cost Effectiveness Analysis for a Complex Airborne Patrol System,** JOSEPH R. GARAFOLA, *ARINC Research Corporation, Annapolis, Maryland.*

**TA3.3** ***Cost Estimates for the Supersonic Transport,** FRANK B. BROWN, *Operations Research Incorporated, Silver Spring, Maryland.*

**TA3.4** ***Application of System Effectiveness Analysis Techniques to an ASW Problem,** R. C. ALBERTSON, *Vitro Laboratories, Silver Spring, Maryland.*

**TA3.5** ***Validation of the WSEIAC Recommended Approach on the Titan II ICBM,** A. J. MONROE *and* J. M. SCHWARZBACH, *TRW Systems, Redondo Beach, California.*

**THURSDAY AM, NOVEMBER 2** LAKE SUPERIOR ROOM

Session TA4: 9:15 AM–Noon

## Applications in Economics

*Chairman:* ROBERT L. GRAVES
*University of Chicago, Chicago, Illinois*

**TA4.1** ***An Infinite Horizon Cash Balance Problem with Proportional Costs,** GARY D. EPPEN *and* EUGENE F. FAMA, *University of Chicago, Chicago, Illinois.*

**TA4.2** ***Efficient Cash Balance Management and Monetary Impact,** DANIEL ORR, *University of California, San Diego, La Jolla, California.*

**TA4.3** ***Continuous and Discrete Time Approaches to a Maximization Problem,** LESTER G. TELSER *and* ROBERT L. GRAVES, *University of Chicago, Chicago, Illinois.*

**TA4.4** ***Approximation Methods for Linear Problems with Imprecise Marketing Data,** A. C. WILLIAMS, *Research Department, Mobil Oil Corporation, Princeton, New Jersey.*

**TA4.5** **A Competitive Bidding Model of the Treasury Bill Auction Market,** ARMANDO ORTEGA-REICHERT, *Varian Associates, Palo Alto, California.*

THURSDAY AM, NOVEMBER 2 LAKE MICHIGAN ROOM

Session TA5: 9:15–Noon

## Health Applications Section
## Operations Research in Health: The Decade Past and the Decade Ahead

*Chairman:* CHARLES D. FLAGLE
*Office of the Surgeon General, U. S. Public Health Service*

TA5.1 ***A Hospital System Planning Model,** DANIEL HOWLAND, *Ohio State University, Columbus, Ohio.*

TA5.2 ***Some Interesting Problems in Medical Operations Research,** ROGER D. PARKER, *Johns Hopkins University, Baltimore, Maryland.*

TA5.3 **Regional Management of Tuberculosis,** C. S. REVELLE, *Cornell University, Ithaca, New York,* W. R. LYNN, *Cornell University, Ithaca, New York, and* F. M. FELDMAN, *Cornell Medical College, New York, New York.*

TA5.4 ***Health Manpower: A Theoretical Framework and an Empirical Application,** RICHARD JELINEK, *University of Michigan, Ann Arbor, Michigan.*

TA5.5 ***Hospital Planning in the Face of Uncertainty,** WILLIAM HORVATH, *University of Michigan, Ann Arbor, Michigan*

THURSDAY AM, NOVEMBER 2 CARACAS ROOM

Session TA6: 9:15 AM–Noon

## OR Techniques I

*Chairman:* RICHARD EVANS
*Case Institute of Technology, Cleveland, Ohio*

TA6.1 **Reneging and Retrials in Queuing Theory: Results and Applications,** P. S. PURI, *Purdue University, Lafayette, Indiana, and* G. SCHWARZBART, *U. S. Department of Agriculture, Forest Service, Berkeley, California.*

TA6.2 **Blocking and Delays in $M^{(n)}/M/C$ Bulk Queuing Systems,** I. W. KABAK, *New York University, New York, New York.*

TA6.3 **Stopping Rules for Queuing Simulations,** IRWIN W. KABAK, *New York University, New York, New York.*

TA6.4 **Computer Simulation of Queuing Models,** G. A. FINKLER, *Equitable Life, New York, New York.*

**TA6.5** **A Heuristic Approach to the Solution of Special Structured Linear Programming Problems,** A. RIESCO *and* M. E. THOMAS, *University of Florida, Gainesville, Florida.*

**TA6.6** **Balas' and Glover's Algorithm: A Comparison,** A. RAO, *Leeds and Northrup Co., Philadelphia, Pennsylvania.*

**TA6.7** **A Max-flow Algorithm for the Design of Reliable Redundant Electronic Networks,** PAUL A. JENSEN, *University of Texas, Austin, Texas.*

**THURSDAY PM, NOVEMBER 2** BOULEVARD ROOM

Session TPL: 12:15–1:45 PM

## Luncheon

*Chairman:* THOMAS E. CAYWOOD
*Caywood-Schiller, Associates, Chicago, Illinois*

Presentation of Cost Effectiveness Prize: FREDERICK S. PARDEE, *The RAND Corporation, Santa Monica, California.*

Presentation of Lanchester Prize: GEORGE E. KIMBALL, *Arthur D. Little, Inc Cambridge, Massachusetts.*

**THURSDAY PM, NOVEMBER 2** CRYSTAL FOYER

Session TP1: 1:45–2:45 PM

## Decision Analysis III

RONALD A. HOWARD
*Stanford University, Stanford, California*

**THURSDAY PM, NOVEMBER 2** CRYSTAL FOYER

Session TP2: 2:45–5:30 PM

## Military Applications Section II Reliability

*Chairman:* JACK R. BORSTING
*Naval Postgraduate School, Monterey, California*

TP2.1 ***Approximations in Some Existing Confidence Interval Estimates of System Reliability,** W. M. WOODS, *Naval Postgraduate School, Monterey, California.*

TP2.2 ***On Confidence Limits for the Performance of a System When Few Failures Are Encountered,** S. C. SAUNDERS, *Boeing Scientific Research Laboratories, P.O. Box 3981, Seattle, Washington.*

TP2.3 ***Reliability Assessment in the Presence of Reliability Growth,** MILTON KAMINS and ALAN J. GROSS, *The RAND Corporation, Santa Monica, California.*

TP2.4 ***Estimation of Failure Rates in Dynamic Reliability,** DAVID RUBINSTEIN, *General Electric Company, Syracuse, New York.*

TP2.5 ***Reliability Demonstration: Methods of Implementation,** D. K. LLOYD, *TRW Systems, Redondo Beach, California.*

**THURSDAY PM, NOVEMBER 2** TROPICAL ROOM

Session TP3: 2:45–5:30 PM

## Simulation

*Chairman:* COSIMO A. CARLUCCI
*Sears, Roebuck and Co., Chicago, Illinois*

TP3.1 ***The Ups and Downs of a (Grain) Elevator Simulation,** ROBERT A SEBASTIAN, *Caywood-Schiller, Associates, Chicago, Illinois.*

TP3.2 **An Application of Simulation to the Evaluation of Alternate Stocking Environments,** G. A. CAHILL *and* G. SHEFFIELD, *Western Electric Co., Inc., New York, New York.*

TP3.3 **Prediction by Simulation of the Reliability and Availability of a Ship System at the Precontract Conceptual Stage,** R. E. IRBY and D. A. REID, *The Stanwick Corporation, Arlington, Virginia.*

TP3.4 **A Model for Analyzing Telephone Costs,** D. A. LEWINSKI, *Bell Telephone Laboratories, Inc., Holmdel, New Jersey.*

**TP3.5** **The Use of Simulation in Studying Information Storage and Retrieval Systems,** R. E. NANCE *and* N. R. BAKER, *Purdue University, Lafayette, Indiana.*

**TP3.6** **Simulation Model of a Computer Controlled Automatic Warehouse,** D. F. THOMPSON, *Ford Motor Co., Dearborn, Michigan.*

**TP3.7** **Scheduling a Multiple Operating Room System: A Simulation Approach,** S. BARNOON, *Blue Cross of Western Pennsylvania, and* H. WOLFE, *University of Pittsburgh, Pittsburgh, Pennsylvania.*

**THURSDAY PM, NOVEMBER 2** LAKE SUPERIOR ROOM

Session TP4: 2:45–5:30 PM

## Network Flows

*Chairman:* T. C. HU
*University of Wisconsin, Madison, Wisconsin*

**TP4.1** ***Recent Advances in Network Flows,** T. C. HU, *University of Wisconsin, Madison, Wisconsin.*

**TP4.2** ***The Relationship Between Network Programming and the Theory of Nonlinear Electrical Networks,** G. J. MINTY, *Indiana University, Bloomington, Indiana.*

**TP4.3** ***Multi-Commodity Network Flows,** B. ROTHSCHILD, *Massachusetts Institute of Technology, Cambridge, Massachusetts, and* A. WHINSTON, *Purdue University, Lafayette, Indiana.*

**TP4.4** ***Shortest Route Methods for Finite State Space, Deterministic Dynamic Programming Problems,** J. F. SHAPIRO, *Massachusetts Institute of Technology, Cambridge, Massachusetts.*

**THURSDAY PM, NOVEMBER 2** LAKE MICHIGAN ROOM

Session TP5: 2:45–5:30 PM

## Duality in Gaming and Programming

*Chairman:* KENNETH O. KORTANEK
*Cornell University, Ithaca, New York.*

**TP5.1** ***Recent Developments in n-Person Game Theory,** W. F. LUCAS, *The RAND Corporation, Santa Monica, California.*

**TP5.2** ***Convex Programming and Systems of Elementary Monotonic Relations,** R. T. ROCKAFELLAR, *University of Washington, Seattle, Washington.*

**TP5.3** ***Generalized Sequential Unconstrained Methods and Duality Results,** ANTHONY V. FIACCO *and* G. P. MCCORMICK, *Research Analysis Corporation, McLean, Virginia.*

**TP5.4** ***Asymptotic Lagrange Regularity with Weak Constraint Qualification,** K. O. KORTANEK *and* J. P. EVANS, *Cornell University, Ithaca, New York.*

**THURSDAY PM, NOVEMBER 2** CARACAS ROOM

Session TP6: 2:45–5:30 PM

## OR Applications II

*Chairman:* DUANE S. DUNLAP
*Aeronautical Systems Division, Wright-Patterson AFB, Ohio*

**TP6.1** **A Generalized Model for the Study of Space Systems Effectiveness,** M. G. BRUNSCHWIG, *Martin Marietta Corp., Denver, Colorado, and* N. B. HILSEN, *Bendix Corporation.*

**TP6.2** **A Monte Carlo Approach to the Planning and Analysis of Space Missions,** F. J. MULLIN, *TRW, Inc., Redondo Beach, California.*

**TP6.3** **The Determination of an Optimum Entry Research Vehicle and Program in a Recent Lifting Body Study,** R. T. SORRELL, *Martin Marietta Corp., Baltimore, Maryland,* H. GILDEA *and* D. W. MEROW, *Peat, Marwick, Livingston & Co., Washington, D. C.*

**TP6.4** **Countdown Decision Aid,** L. R. GUTSTADT, *North American Aviation, Inc., Downey, California.*

**TP6.5** **Mathematical Model for Aerospace Maintenance,** C. M. RIEHL, *North American Aviation, Downey, California.*

**TP6.6** **Manned Flight Awareness, An Employee Motivation Program For Manrated Space Vehicles,** M. R. SHARPE, *National Aeronautics and Space Administration, Huntsville, Alabama.*

**FRIDAY AM, NOVEMBER 3** Crystal Foyer

Session FA1: 8:15–9:15 AM

## Decision Analysis IV

Ronald A. Howard
*Stanford University, Stanford, California*

**FRIDAY AM, NOVEMBER 3** Tropical Room

Session FA2: 9:15 AM–Noon

## Cost Effectiveness Section III
## Cost Analysis Applications

*Chairman:* John W. Locke
*Consultec Division, NUS Corporation, Washington, D. C.*

**FA2.1** ***Defense System Support Costs as Related to Project PRIME,** J. Jarret, *Planning Research Corporation, Washington, D. C.*

**FA2.2** ***Cost Model Development for Transportation Systems,** P. Dienemann, *Resource Management Corporation, Bethesda, Maryland.*

**FA2.3** **Cost Analysis of "In Production" Systems,** Arnold Klick, *NUS Corporation, Washington, D. C.*

**FA2.4** ***Data Problems in Deriving Cost Estimating Relationships for Ship Procurement,** C. Sites, *Resource Management Corporation, Bethesda, Maryland.*

**FA2.5** **Cost Estimating Relationships for Military Helicopter Airframe Procurement,** Mary Biagioli, *U. S. Army Aviation Materiel Command, St. Louis, Missouri.*

**FRIDAY AM, NOVEMBER 3** CRYSTAL FOYER

Session FA3: 9:15 AM–Noon

## Military Applications Section III

Panel Discussion: "Operations Research and the Challenge of Conflict in the Last Third of the Century"

*Chairman:* THOMAS W. GEORGE, *North Carolina State University, Raleigh, North Carolina*

*Panelists:* ANATOL RAPOPORT, *Department of Biology, University of Michigan, Ann Arbor, Michigan.*

NICHOLAS M. SMITH, *Department of Advanced Research, Research Analysis Corporation, McLean, Virginia.*

ROBERT E. MACHOL, *School of Business, Northwestern University, Evanston, Illinois.*

WARREN S. MCCULLOCH, *Electronics Research Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts.*

(Abstract **FA3** contains an outline of the subject matter for this panel discussion.)

**FRIDAY AM, NOVEMBER 3** LAKE SUPERIOR ROOM

Session FA4: 9:15 AM–Noon

## Non-linear and Probabalistic Optimization Techniques

*Chairmen:* W. M. RAIKE
*Northwestern University, Evanston, Illinois*
AND
M. KIRBY
*Dalhousie University, Halifax, Nova Scotia, Canada*

**FA4.1** ***Optimal Maintenance Policy and Sale Date of a Machine,** G. L. THOMPSON, *Carnegie Institute of Technology, Pittsburgh, Pennsylvania.*

**FA4.2** ***A Branch-and-Bound Algorithm for Multi-level Fixed-Charge Problems,** A. P. JONES *and* R. M. SOLAND, *Research Analysis Corporation, McLean, Virginia.*

**FA4.3** ***Separable Markovian Decision Problems,** E. V. DENARDO, *RAND Corporation, Santa Monica, California.*

**FA4.4** ***An Algorithm for a Class of Dynamic Linear Programs,** R. GLASSEY, *University of California, Berkeley, California.*

**FA4.5** ***Geometric Programming: A Unified Quality Theory for Quadratically Constrained Quadratic Programs and $l_p$-constrained $l_p$ Approximation Problems,** E. L. PETERSON, *University of Michigan, Ann Arbor, Michigan.*

**FA4.6** **Use of Geometric Programming to Maximize the Reliability Achieved by Redundancy,** M. MAZUMDAR *and* A. J. FEDEROWICZ, *Westinghouse Research Laboratories, Pittsburgh, Pennsylvania.*

**FRIDAY AM, NOVEMBER 3** LAKE MICHIGAN ROOM

Session FA5: 9:15–Noon

## OR Applications III

*Chairman:* DONALD H. SCHILLER
*Caywood-Schiller, Associates, Chicago, Illinois.*

**FA5.1** **Project Selection under Cost and Pay-off Value Uncertainties,** T. S. CHIDAMBARAM, B. V. DEAN *and* R. R. PALANKI, *Case Institute of Technology, Cleveland, Ohio.*

**FA5.2** **Planning New Manufacturing Operations,** R. A. WALD, *Lockheed Missiles &, Space Co., Sunnyvale, California.*

**FA5.3** **Discrete Dynamic Programming and Capital Allocation,** G. L. NEMHAUSER *and* Z. ULLMAN, *The Johns Hopkins University, Baltimore, Maryland.*

**FA5.4** **Alternative Approaches to the Measurement of Risk,** J. L. BICKSLER *and* J. MCGUIGAN, *Ford Motor Credit Company, Dearborn, Michigan.*

**FA5.5** **Production Testing Equipment Cost-optimization,** W. D. HERD, *Hughes Aircraft Co., Los Angeles, California.*

**FA5.6** **Applications of Game Theory Models in Agriculture,** E. O. HEADY *and* R. C. AGRAWAL, *Iowa State University, Ames, Iowa*

**FA5.7** **A Case Study of Optimizing Production and Inventory Levels,** J. MUELLNER, *Automatic Electric Co., Northlake, Illinois.*

**FA5.8** **Forecasting Research Budgets in an Industrial Organization,** B. V. DEAN, S. H. MANN *and* B. D. CORWIN, *Case Institute of Technology, Cleveland, Ohio.*

**FRIDAY AM, NOVEMBER 3** San Juan Room

Session FA6: 9:15–Noon

## OR Techniques II

*Chairman:* Irwin Boris
*Montgomery Ward and Company, Chicago, Illinois*

**FA6.1** **The Probability of an Equilibrium Point,** A. J. Goldman *and* K. Goldberg, *National Bureau of Standards, Washington, D. C.*

**FA6.2** **Optimization of a Periodic Markov Chain with Return,** E. R. Petersen, *National Energy Board, Ottawa, Canada.*

**FA6.3** **Adaptive Smoothing Using Evolutionary Spectra,** A. G. Rao, *and* A. Shapiro, *Mobil Oil Corp., New York, N. Y.*

**FA6.4** **Integer Cutting Stock Problems,** C. J. Tompkins, *Virginia Polytechnic Institute, Blacksburg, Virginia.*

**FA6.5** **A Stationary Problem for a Multi-Commodity Inventory System with Interacting Set-up Costs,** B. D. Sivazlian, *University of Florida, Gainesville, Florida.*

**FA6.6** **Operations Research Techniques in Purchasing,** S. F. Dinerstein *and* L. R. Hagood, *Western Electric Company, New York, N. Y.*

**FRIDAY PM, NOVEMBER 3** Tropical Room

Session FP1: 1:30–4:30 PM

## Cost Effectiveness Section IV

*Chairman:* John W. Locke
*Consultec Division, NUS Corporation, Washington, D. C.*

**FP1.1** **More on the Discount Rate,** H. L. Eskew, *Planning Research Corporation, Washington, D. C.*

**FP1.2** **Academic Planning with Progrm Budgeting,** P. W. Hamelman, *West Virginia University, Morgantown, West Virginia.*

**FP1.3** **Systems Analysis and Cost Effectiveness—A Rehabilitation Program Example,** G. K. C. Chen *and* S. Young, *School of Business Administration, University of Massachusetts, Amherst, Massachusetts.*

**RP1.4** **State of the Art Survey of Methods of Cost Effectiveness Evaluation,** Mary Biagioli *and* Major Roger F. Meissner, *U. S. Army Aviation Materiel Command, St. Louis, Missouri.*

**FP1.5** **Helicopter Component Interrelationships with Design Parameters,** Michael B. Bryant, *U. S. Army Aviation Materiel Command, St. Louis, Missouri.*

**FP1.6** **Weighting for Lot Size in the Learning Curve Exponent Determination,** F. J. Dahlhaus, *Headquarters U. S. Army Materiel Command, Washington, D. C., and* Norman Smith, *U. S. Army Aviation Materiel Command, St. Louis, Missouri.*

**FRIDAY PM, NOVEMBER 3** Crystal Foyer

Session FP2: 1:30–4:30 PM

## Military Applications Section IV
## Contributed Papers

*Chairman:* William A. Carswell
*Carswell, Vandiver & Assoc., Inc. Alexandria, Virginia*

**FP2.1** **An Analysis of A Decision Making Process,** C. Richard Conger, *HRB Singer, Inc., State College, Pennsylvania.*

**FP2.2** **The Equivalence of Two Objective Functions for Optimal Missile Allocation,** R. Emerson Thomas, *Bell Telephone Laboratories, Whippany, New Jersey.*

**FP2.3** **ECM-Oriented Penetration Model,** G. A. Fleischer, *University of Southern California, Los Angeles, California,* M. Hersh, *Stevens Institute of Technology, Hoboken, New Jersey, and* D. L. Magnuson, *U. S. Naval Missile Center, Pt. Mugu, California.*

**FP2.4** **Multi-echelon Stockage Model for Aircraft Spares,** W. M. Faucett, L. J. York *and* R. D. Gilbert, *General Dynamics Corp., Ft. Worth, Texas.*

**FP2.5** **The Contingency Transportation Requirement-System,** Carlton Combs, Jr., Ed. Hammelman, *and* Charles Spasaro, *Technical Operations, Inc., Arlington, Virginia.*

**FP2.6** **An OR Approach to the Counterbattery Problem,** Leon Sembach, *Technical Operations, Inc., Alexandria, Virginia, sponsored by* E. B. Vandiver, *Carswell, Vandiver & Assoc., Inc., Alexandria, Virginia.*

**FP2.7** **A Dual-State Force Planning Cost and Specification Model,** O. Bryk, J. Phillips *and* C. Robertson, *Research Analysis Corporation, McLean, Va.*

**FP2.8** **A Decision-Theoretic Analysis of the President's Vietnam Problem,** Lawrence Harris, *New York University, New York, New York.*

**FRIDAY PM, NOVEMBER 3** SAN JUAN ROOM

Session FP3: 1:30–4:30 PM

## OR Applications IV

*Chairman:* ROBERT E. MACHOL
*Northwestern University, Chicago, Illinois*

FP3.1 **OR and Computer Emphasis in Curriculum of Leading Schools of Business,** J. D. COUGER, *University of Colorado Boulder, Colorado.*

FP3.2 **OR in an International Business Curiculum,** HERBERT GLAZER *Sophia University, Tokyo, Japan.*

FP3.3 **Optimal Sequencing of Second Language Instruction: An O. R. Approach,** C. SCHOTTA, JR. *and* S. G. SCHOTTA, *University of California, Davis, California.*

FP3.4 **A Transportation Model of Racial Desegregation in School Systems,** S. CLARK, *Columbia University, New York, N. Y., and* J. SURKIS, *Sperry Rand Corp., New York, New York.*

FP3.5 ***Systems for Planning Urban and Social Change,** D. F. BLUMBERG, *Philco-Ford Corporation, Fort Washington, Pennsylvania.*

FP3.6 **Employment of Operations Research in Hospital Design,** P. S. HORWITH, *TRW Systems, Redondo Beach, California.*

FP3.7 **Strategic Planning and Management Information Systems,** I. BORIS, *Montgomery Ward and Company, Chicago, Illinois.*

FP3.8 **A Working Plan for Programming and Sustaining Growth of Small Scale Industries Around Calcutta, India,** B. P. BANERJEE, *MacNeill & Barry, Ltd., Calcutta, India.*

FP3.9 **Computer Simutations to Assist Rational Resources Allocation in Health Sciences Education,** S. CENTNER, W. WOLFSON, J. WATTER *and* R. WILSON, *Health Sciences Functional Planning Unit, University of Toronto, Toronto, Canada.*

# Abstracts

**WA1.1 *An Assembly Line Simulator,** COLIN L. MOODIE, *Purdue University Lafayette, Indiana.*

The operation of an assembly line, balanced to the minimum balance delay criterion, is simulated to observe the effect that work task variability, and worker learning have on assembly line system performance. The simulation represents the operation of an actual line in the appliance industry. Line performance when balanced to criteria other than minimum balance delay are discussed, and an alternate criterion is proposed for minimizing per unit output cost from the assembly line.

**WA1.2 *A Study of The Robustness of Assembly Line Production Rates With Respect To Allocation of Work Between Stations,** RONALD W. BOLING PH.D., *The University of Tennessee, Knoxville, Tennessee.*

The allocation of work between stations of an assembly line, or relative balance of the line, is one factor affecting system production rates. This study shows that when work is allocated to take advantage of the "bowl phenomenon" the expected production rate of the system is very robust with respect to lack of balance for those cases where inventories between stations are limited and the distribution of station operation times is such that the ratio of the variance to the mean is relatively large. The finite series queue model was used to obtain analytical results for assembly lines with up to seven stations, both with and without provision for in-process inventories. Several cases of the Erlang distribution were assumed for station operation time distributions to show the effect of the ratio of variance to mean on the robustness of assembly line production rates. The economic significance of these results is noted.

**WA1.3 A Heuristic Approach To Assembly Line Balancing,** JAMES L. ÇNOSSEN, *Ford Motor Company, Dearborn, Michigan.*

This paper discusses the problem of developing work assignments for operators stationed on conveyorized assembly lines having an adjustable cycle time. The complexity of this problem is substantially increased by attempting to achieve the typical line balancing objective of maximizing the utilization of direct labor involved within the constraint of minimum perturbation upon rebalance. •Minimum perturbation is defined as the attempt to prevent the re-location of relatively fixed facilities on the assembly line and an attempt to utilize as much as possible the existing skills of the assembly operators. Rigorous mathematical optimizing techniques were investigated but were found to be impractical in achieving the above objectives in a relatively complex assembly situation because many of the qualitative variables could not be represented in quantitative form for consideration by the technique. Accordingly, a heuristic was developed and programmed to achieve the above mentioned objectives within such typical line balancing constraints as precedence ordering of the work tasks and cycle time limitation. A synopsis of the balancing heuristic is given together with a discussion on its use as a simulation model of an assembly process to test the effect on assembly manpower of alternate facilities layouts and to develop the maximum production level for a fixed manpower requirement.

**WA1.4 * ALPS—An Assembly Line Planning System,** Norman J. Burkard, *General Electric Company, Schenectady, New York.*

The prime output of any assembly line planning system is the allocation of work to the operators along the assembly line—commonly known as 'Assembly Line Balancing.' Existing computer programs (known to the author) used to accomplish this activity have fallen into disuse for a variety of reasons; foremost being, the creation and maintenance of precedence (balloon) charts. This paper will describe a total assembly line planning system utilizing the computer for balancing assembly lines, for maintenance of data files and for generation of work element precedence relations. A technique of computer 'Learning' of precedence relationships, including the maintenance of this information under conditions of change will be covered in depth. Operating results of the system, for assembly lines working in the mixed-model mode will be reported and suggested system improvements will be discussed.

**WA1.5 A Heuristic Branch and Bound Technique for Line Balancing,** N. Richard Reeve and Warren H. Thomas, *Department of Industrial Engineering, State University of New York at Buffalo, Buffalo, New York.*

This paper presents the development and testing of a heuristic technique for solving the line balancing problem. This technique incorporates the following decision rules. (1) Consider only the "most promising alternatives" at each work station. (2) Employ a variable overlapping progression, which recursively sub-optimizes over an arbitrary number of work stations. Phase I of the heuristic technique attempts to obtain a minimum station balance for a given set of operating conditions. Phase II attempts to apportion the idle time equally over all stations by recursively resetting the operating conditions and reapplying Phase I. Application of the heuristic technique on five line balancing problems has served to demonstrate the value of the procedure.

**WA1.6 * On Criteria for Assigning Models to Assembly Lines,** Melvin Lehman, *IIT Research Institute, Chicago, Illinois.*

The advantages of progressive assembly of products has been evident to industry for many years. Recently, customer demands have been for a wide variety of models of a product. In response to these demands, many assembly lines have been changed over to handle assembly of more than one model of a product inter-mixed on the same line. The problem addressed in this paper is that of assigning the models to mixed model assembly lines so as to minimize the costs associated with a particular mix of models on a line. In order to consider a problem of this type, criteria are developed which represent costs affected by mixed model assembly. The criteria included are learning, balance delay, nonproductive work, and inefficiencies resulting from mixing of models. Each of the criteria is defined and analytic models developed. Several new concepts are introduced in this paper including a mixed model learning curve, a measure of model similarity, and determination of work station size. When all criteria are combined, the result is a quantitative measure of assignment effectiveness in terms of predicted mixed model assembly costs. Typical applications are shown demonstrating the consequences of the model, and its scope of utilization.

**WA1.7 *Stocking An Automotive Assembly Line,** W. B. Moore, *International Harvester Co., Chicago, Illinois.*

This is a system consisting of computer programs and a small amount of clerical effort to generate parts stocking requirements by stations along an automotive assembly line. The computer programs consider both the assembly schedule for vehicle of a wide variety and the parts supply along the line. This includes both purchased material and in plant manufactured components.

**WA1.8 Sequence Dependent Set-Up Times: A Prediction Method and an Associated Technique for Sequencing Production,** Charles Herbert White, *E. I. DuPont de Nemours Co., Inc., Wilmington, Delaware.*

A model is developed for predicting set-up times on machine tools that considers the dependency of the set-up times on the sequence in which the products are manufactured. This model is illustrated using a case study with initial and validation samples. A classification system is developed for the predictive model and is then used as the basis for an approximate technique for sequencing a closed set of jobs on a single machine so as to minimize the aggregate set-up time. The classification system is used to identify subsets of jobs, and then the relative values of the predictive model coefficients are used to select from among the subsets the subset to be next added as a sequence is constructed. The total set of jobs is partitioned and a partial sequence is built up step by step until all of the jobs are included and the final production sequence is established.

**WA2.1 Operations Analysis in the Mediterranean H-Bomb Search,** Dr. Henry R. Richardson, *Daniel H. Wagner, Associates, Paoli, Pennsylvania.*

The underwater search for the lost H-bomb was evaluated through the use of search effectiveness probability (SEP) as a measure of effectiveness. SEP is defined as the probability that if the target (H-bomb) were in a given region (e.g., one of the cells into which the search region was decomposed) with a particular a-priori distribution, then it would have been located with a specified amount of search effort. This measure was useful in helping to determine when an adequate amount of effort had been applied to a particular region and in choosing regions to be searched next. This paper discusses the methods used in computing SEP with particular emphasis on the considerations impinging upon determination of the a-priori distributions for the target's location and the influence of navigational errors on search effectiveness. The search systems employed are discussed along with their specific capabilities and contributions. The progress of the operation is shown by charts presenting SEP at critical periods in the search.

**WA2.2 A Reliability Based Measure of System Effectiveness,** M. E. CAPEHART and J. K. HANCOCK, *Martin Marietta Corp., Denver, Colorado.*

Successful planning of large scale systems cannot be performed without a stated or implied measure of effectiveness to be used in the evaluation of alternative system configurations. Often, however, such measures are devised without consideration of the possible degradation of effectiveness brought on by failures of certain system components. System planning with reliability as a basis enables the identification of sensitivity to reliability, and enables the planner to design a system which optimizes expected return rather than a measure of return for which no level of confidence is known. The algorithms presented represent a systematic and general purpose technique by which one may (a) measure expected system effectiveness, (b) obtain a level of confidence in the measure and (c) determine areas of sensitivity or criticality in the system. Through the application of this approach to system effectiveness the planner is able to develop plans based on operational effectiveness, rather than some "best case" approximation. The paper presents the algorithms sample problems and describes the use of the techniques on a space program.

**WA2.3 The Fire Allocation Problem,** DANIEL O. ETTER, JR., *Institute for Defense Analyses, Arlington, Va.*

Consider a unit in combat. It may be confronted by more than one target (or target concentration). The unit must allocate its fire among its possible targets in some way. Optimal allocations of fire are derived under the assumptions that: (1) units allocate their fires independently; (2) attrition follows a Lanchester linear law or square law. The analysis proceeds as follows. First the appropriate Lanchester-like system of equations for combat of one unit against two units is written down. Next, the system is transformed in such a way that the identity of the optimal allocations becomes obvious. It is then remarked that the result generalizes trivially to the case of one unit against any finite number. A verbal statement of the result is that a unit should allocate its fire to reduce the threat to itself as rapidly as possible. Some numerical comparisons of the results of different allocations are shown.

**WA2.4 Optimal Attack of a Communications Network,** MANDELL BELLMORE, HARVEY GREENBERG and JOHN JARVIS, *Johns Hopkins University, Baltimore, Maryland.*

The problem of attacking a communications network is considered. We assume that associated with each arc of the network is a cost to destroy that arc, and associated with certain node pairs is a value of destroying all chains between that node pair. We are concerned with finding an attack which maximizes the value of disconnected nodes subject to a budget constraint. We present a 0-1 programming formulation and some computational experience. When the budget is unlimited, the problem becomes that of finding a minimum disconnecting set for a multi-commodity flow problem.

**WA2.5 Life Distributions Derived From Stochastic Hazard Functions,** CARL M. HARRIS, *Research Analysis Corporation, McLean, Virginia,* and NOZER DARABSHA SINGPURWALLA, *Western Electric Company, Incorporated, Engineering Research Center, Princeton, New Jersey.*

Most of the familiar time-to-failure distributions used today are derived from hazard functions whose parameters are assumed to be constant. In this paper, we derive an unconditional time-to-failure distribution by assuming that a parameter of classical failure distribution (viz., exponential and Weibull) is a random variable with a known distribution. With the use of the derived compound distributions and Bayesian techniques, it is then possible to join the test data with prior information to arrive at a combined, and possibly superior, estimate of reliability. The prior distributions considered here are the two-point, the uniform and the gamma. Conceptually, such a scheme may be a more realistic model for describing failure patterns under specific conditions.

**WA2.6 Warehouse Space Estimation,** BURNHAM S. GOULD, JR., *General Mills, Inc., Minneapolis, Minnesota.*

General Mills has developed a basic inventory model called PILE (Product Inventory Level Estimator), which incorporates both modern inventory control theory and plant operating practices. The model estimates warehouse space requirements, by product, for a wide range of possible operating and environment conditions. Optional features give the model great flexibility in types of input data used, in output reports, and in management applications. For the past three years PILE has been the principal tool used at General Mills for forecasting future warehouse requirements, and for evaluating the effects on inventory levels of various configurations of producing and warehousing locations. As management's confidence in PILE increased, it began playing a major role in determining distribution policy, especially in such areas as the establishment of target stockout rates and of customer service time standards. PILE has now become the principal tool used in determining optimum warehouse layouts. Recently, we have started using PILE as a current operating tool for controlling the level and location of inventories within a warehouse.

**WA2.7 A Computer Simulation of a Linen Supply Plant,** DAVID ALLEN, and JOHN P. KOWAL, *Dunlap and Associates, Inc., Darien, Connecticut.*

The purpose of this study was to build a computer simulation of a linen supply plant in order to evaluate the cost of processing any vector of soiled linen. A Linen Supply plant is represented by six work centers; sorting and receiving, washing and extracting, tumbling and preconditioning, folding, ironing, and pressing. The cost of labor used at each work center is evaluated for each vector of soiled linen. To calculate the costs of materials, electricity, water, power, repairs, and depreciation, an average cost for each of these materiels is used and knowing the weight of the soiled linen to be processed the costs of these materiels is calculated. The total cost is found and costs for individual items is then calculated. The cost for processing an item is compared with the retail price and the profit or loss per item is found.

**WA2.8 Nuclear Warfare Analysis and the Scientific Process,** STANLEY COHEN, *TRW Systems, 600 East Mill Street, San Bernardino, California.*

Natural science is distinguished by validation of hypothesis by experiment. Although, O. R. is thought of as a natural science, papers presenting experimental verification of results are rare, while O. R. papers on nuclear warfare which present experimental verification are non-existent. Thus the questions arise:

1) Is nuclear warfare analysis a natural or social science?
2) How can nuclear warfare analyses be verified?

The following is argued. Insofar as irrational acts can be analyzed, nuclear warfare analysis is primarily a social science. The analysis should deal with human intent as well as system mathematics. The intent, however, will be conditioned by the credence attached to such elements as AICBM, civil defense, positive control, and rapid decision time. Intent may be studied by laboratory games and in-depth interviews. It is further argued that major problems should be analyzed by independent studies with iteration after feedback. The standard for validation of results is the rough consensus achieved by a multiplicity of briefings and rebriefings. Finally, it is argued that the most useful mathematical contribution to nuclear analysis is the development of simple formulas illustrating pertinent forcing functions. (Three examples are given)

**WA3.1 *Stability of a Car-Following Model with Variable Time Delay,** LUCIEN DUCKSTEIN, ESTAN F. INLER and ERNEST A. UNWIN, *University of Arizona, Tucson, Arizona*

Stability considerations and physiological phenomena indicate that both relative distance and relative speed are used as cues by the driver of a following car. However, it is difficult to determine the relative importance of each cue. On the assumption that this relative importance is independent of the state of the system, a reciprocal-spacing type model has been proposed in which the stimulus is a linear combination of relative speed and relative velocity. To facilitate stability analysis, an "ideal" following distance is introduced into the model so that the dependent variable represents deviation from ideal or steady-state behavior. Experimental results obtained by a traffic study group within the Systems Engineering Department are analyzed to estimate the parameters of the model. The effective weights of the relative speed and relative distance cues are determined. The functional form of the "ideal" following distance as a function of absolute velocity is discussed and some indication is given as to the distribution of this random variable for a limited population of drivers. Finally, a functional form for the time delay in the response is proposed and the effect of this non-constant delay upon the system stability is analyzed.

**WA3.2 *A Discrete Model of Vehicular Traffic,** MICHAEL C. DUNNE and RICHARD W. ROTHERY, *General Motors Research Laboratories, Warren, Michigan*, and RENFREY B. POTTS*, *University of California, Berkeley, California.*

For a number of years the Poisson process has been assumed to be a suitable model to describe the time series of events of vehicles passing a point on a roadway. However, on a two lane facility, for example, it is well known that bunching occurs in that the observed frequency of headways in the range of one to about six seconds is greater than that predicted by the Poisson process. In addition the Poisson model does not take into account the finite size of the model. This paper proposes

* Permanent address: The University of Adelaide, South Australia.

a Markov model for describing the generation of this time series of events. The model is an extension of the simple binomial model in that it allows for correlations between successive vehicles and therefore can account for the bunching of traffic. A description is given of the arrival time experiments which were carried out to test the model and the statistical analysis of the results of these experiments is discussed. In addition, several theoretical aspects of the model are examined.

**WA3.3 *Surveillance and Control of Tunnel Traffic by an On-Line Digital Computer,** Robert S. Foote, *The Port of New York Authority, New York,* and Denos C. Gazis, *IBM Research Center, Yorktown Heights, New York.*

An experimental surveillance and control system is currently in operation for one lane of the Lincoln tunnel in New York City. The system shares in the use of an IBM 7040 computer located at the IBM Research Center. The computer receives via a telephone line signals from pairs of detectors located at four observation points along the tunnel. From these signals are determined the average densities in three sections of the tunnel, as well as the speed and throughput over the four observation points, at discrete time intervals. The objective of the control system is to reduce the input of traffic into the tunnel when needed in order to prevent congestion which has been shown to reduce appreciably the throughput of the tunnel. A discussion will be given of the algorithms used for such control and the results to date.

**WA3.4 *q's and Q's,** A. May, G. F. Newell, R. M. Oliver and R. B. Potts, *University of California, Berkeley.*

If a highway system is to be used for both public (buses) and private (cars) transportation, it is often advantageous to give some type of priority service to buses. Since severe congestion is usually confined to only a few critical sections of a highway or to some critical bottlenecks, a priority scheme for service of these bottlenecks could have a significant effect upon the total passenger delay in the entire highway system. We consider two related types of strategies. First, suppose that on a finite section of a multilane expressway there is a total flow $q$ and no queue $Q$ at the entrance or exit. If buses are given one or more lanes for exclusive use, it is possible to achieve a higher velocity for buses but a lower velocity for cars than would exist under mixed operation at the same total flow. The higher velocity for buses, each carrying many passengers, will in many cases off-set the increased delay to car passengers. Secondly, if a queue does exist at a bottleneck then there are various queue disciplines which might be applied to keep the queue of buses as low as possible, at the expense of the cars. Strategies of first-come-first-served, priority service, and separate service for buses are compared under the condition of a heavy rush-hour demand.

**WP2.1 *A Survey of Search Theory,** James M. Dobbie, *Arthur D. Little, Inc., Cambridge, Massachusetts.*

A brief review of known results in the theory of search will be made to introduce the subject of the session and to provide background for the papers that follow. The review will be followed by a discussion of a sequence of problems on the optimal distribution of searching effort, some of which have been solved recently and some of which have not been solved.

**WP2.2 *Search and Information Theory,** B. O. KOOPMAN, *Columbia University, New York, N. Y.*

The problem of finding a point (target, position in system space, etc.) of known probability distribution, hinges on the law of detection—how a given element of effort applied in a given way produces a probability of detection. Once this law is known, a sequential optimization of detection can be established. When this is layed on, the expected effort until detection (possibly infinite) may be taken as a measure of the difficulty of the searching task. It will depend on the a priori probability distribution of the target, and may be regarded as its uncertainty or "entropy"—relative to the detection law in question. Its negative may be called the corresponding "information." This concept leads to the classical logarithmic formula for information in cases where the detection law is by dichotomies and the distribution a discrete one; and to the two-distribution cross-entropy in the continuous case. It leads to formulas of practical relevance in the case of the law of random search.

**WP2.3 *Search, Detection and Subsequent Action: Some Problems on the Interfaces,** STEPHEN M. POLLOCK, *Naval Postgraduate School, Monterey, California.*

Surveillance operations in general involve a search *procedure*, the occurrence of *events* such as detections and false alarms, and as a consequence, subsequent *decisions* leading to action of some kind. There has been a tendency to model the three phases of search, detection and action separately, albeit the output parameters of one model often are used as the input of another. This paper considers some of the problems involved in describing the interfaces between these phases, and includes a discussion of

a. the role of false alarms in the effectiveness of search procedures;
b. problems contingent in modelling of continuous surveillance processes;
c. relations between localization and detection capability;
d. measuring the effectiveness of sequential detection strategies.

**WP2.4 *Surveillance Guided Search,** GEORGE E. KIMBALL, *Arthur D. Little, Inc., Cambridge, Massachusetts.*

If a target is operating in a surveillance field, the field provides information about the target position which may be expressed as a probability density which is a function of position and time. If we consider a search conducted by a moving search vehicle for such a target, then the information gained by the search vehicle must be continually combined with the information from the surveillance field if the search is to proceed efficiently. Optimum search procedures have not been devised, and probably never will be except in trivial cases. Nevertheless there are limiting cases whose approximate solutions are available, and which provide useful limits to the probability of success in real situations.

**WP2.5 *Search Games,** Rufus Isaacs, *Center for Naval Analyses, Arlington, Virginia.*

When we not only seek an optimal search method, but assume the hider also strives for the best mode of concealment, we have a two sided contest called a search game. With mobile searchers and hiders, it can be regarded as the limiting case of a pursuit game with partial information when the latter is zero. As generally with search games the optimal strategies will be mixed (in the sense of game theory), they often constitute problems much more difficult than one-sided search procedure. Accordingly, present understanding is rather limited. This talk will cover some simple cases that have been solved, present some cogent others that have not, distinguish aspects of the solution that are essential from those that are not, and motivate the need for more research effort.

**WP3.1 *Research Allocation—The Problem and Its Environment,** Frederick S. Pardee, *The RAND Corporation, Santa Monica, California.*

Some would assert that there is a need for application of more precise criteria in evaluating research being supported in the earlier phases of the military research and development process. A difficulty emerges, however, in attempting to develop meaningful, comprehensive measures of potential value. Historically, science has found its way into technology and technology into weapon systems only over the long term. It is extremely difficult to define military threats of the distant future with sufficient precision to suggest future hardware and hence identify current research needs. Any systematic allocation method which is developed must, explicitly or implicitly, quantitatively or qualitatively, incorporate a host of factors—technical, administrative and sociological. Freedom and flexibility are important to the scientist not only from the standpoint of actual pursuit of promising opportunities, but also frequently because he needs to feel unfettered in order to be creative. On the other hand, from an administrative standpoint, basic research for the Department of Defense alone is a $300–400 million annual expenditure and it is composed of several thousand individual research projects upon which allocation decisions must be made. In addition, national security objectives and technological potential are both highly dynamic. It would appear, therefore, that some system for identifying with overall goals and implementing research strategies would indeed be helpful in such a decisionmaking environment.

**WP3.2 *Research Allocation—A Method for Linking Defense Sciences, Technologies and Missions,** Major Joseph P. Martino, *Air Force Office of Scientific Research, Arlington, Virginia.*

The method described in this paper is based on the assumption that the key concept in allocating resources to areas of science and technology is *balance*. The central problem is to define a measure of utility which can be applied to all programs or projects which are in competition for funding. Numerical priority weights are applied to Operational Capability Objectives for each time frame. The level of technological capability necessary in each subsystem, component and technology required is identified, its level of difficulty estimated, a criticality number assigned, and a budget plan generated. Extension of the method to basic research is accomplished by developing criticality, timing and cost estimates for new knowledge required in each scientific area in order to permit technological advances. Committees of systems analysts, technologists and others would be assembled to generate the required information. The method would be operated utilizing linear programming techniques.

**WP3.3 Research Allocation—The Contribution of Resource Allocation Theory and Marginal Analysis,** EDWIN V. W. ZSCHAU, *Harvard Graduate School of Business Administration, Boston, Massachusetts* and HENRY B. EYRING, *Stanford University, Graduate School of Business, Palo Alto, California.*

The approach in this paper is to describe a simplified theory of research budgeting based on well-known ideas of resource allocation. Based on the theory, an "ideal" or optimization method is suggested. Next, reasons are investigated why a method such as this is not currently being used in making allocation and project selection decisions for basic research programs. Investigations reveal several characteristics inherent in the research budgeting problem that prevent such a method from being used. Finally, two modifications to the ideal procedure that might be implemented are suggested. These require inter-project comparison only and are based on the analysis of marginal projects. Although these adaptations would not necessarily lead to optimal budget levels and project selections, they could detect and eliminate any gross misallocations of research funds that may exist. In a problem so plagued by valuation difficulties and uncertainty as the research budgeting problem is, even such modest improvements could significantly increase the overall effectiveness of the decisionmaking procedures.

**WP3.4 *Research Allocation—A Decision Model Under Uncertainty,** NILS H. HAKANSSON, *Yale University, New Haven, Connecticut.*

In this paper, an approach based on modern decision theory to the problem of determining the allocation of funds among research activities is explored. An environment of uncertainty is assumed; as a result probability estimates and a utility function constitute sufficient inputs for a solution to this allocation problem. In developing these inputs, the structure of interdependencies among the activities is shown to provide a basis for a division of labor and a reduction in the amount of work required, both of which may be highly significant. In any case, needs and opportunities may always be evaluated by separate individuals. Under weak assumptions, an individual estimator always runs the risk of losing if he tries to "estimate" in such a way as to secure a larger allocation for himself. The approach also considers, implicitly, such factors as minimum threshold levels and variations in risk between projects.

**WP3.5 *Research Allocation—Query Techniques, Panels of Experts and Sociometric Considerations,** HOWARD A. WELLS, *Bell Aerosystems Company, P.O. Box 1, Buffalo, New York.*

This paper presents exploratory notions on a theory of query and its application to the problem of accumulating and combining the subjective judgments necessary as inputs to systematic analysis of preferred research allocations. Techniques for design of questions, measurement and ranking, elimination of bias, weighting of degree of expertness, etc., are considered. Questionnaires, interviews, and informal automated techniques for dealing with panels of experts are discussed, with emphasis on psychological and sociological as well as the purely quantitative aspects of the problem. Identified are special considerations associated with overcoming reluctance of participating scientists and engineers. Also, referenced is the importance of careful structuring of the precise information required as input to a given model or models.

**WP3.6 *Research Allocation—Framework for a Comprehensive Analytic Method,** CHARLES P. BONINI, *Stanford University, Palo Alto, California.*

General criteria about the worth of basic research in our society are necessary background for development of any technique for allocating funds. For a mission-oriented agency, such as the Department of Defense, the major criterion should be to maximize the contribution of the product of the research to the achievement of the agency's goals. A model is discussed in which the value of various goals of an agency are measured and the worth of the basic research questilns valued in terms of these goals. The model takes explicit account of the uncertainties involved in research and development and of the fact that the research is related to projects in different periods of time. A method for allocating funds between various sciences and technologies is presented. This involves the programming or scheduling of basic research projects as well as funds for allocation. In this paper important major dimensions of the problem are identified and structured in a systematic fashion.

**WP4.1 A Transportation Scheduling Model,** JERRY H. HOGAN and LUCIEN DUCKSTEIN, *Systems Engineering Department, The University of Arizona, Tucson, Arizona.*

A model has been developed to generate schedules of movements for a medium size transportation corporation faced with the problem of delivering bulk goods from various origins to a variety of destinations. The model develops a schedule of movement based on policies supplied by the corporation. Input to the model includes mover and node characteristics, cargo to be scheduled, the time frame of the schedule, the initial "state" of each mover, and the policies of the corporation. Decisions on vehicle movements are made when critical dates occur. Times for all vehicle movement, loading and unloading, are based on average values supplied by the corporation; no stochastic variables are generated. The model, written in FORTRAN II, can be adapted to fit most transportation scheduling type problems. A case study of ten vehicles servicing ten nodes was made for a ninety day period. Considering each vehicle in increments of one tenth of a day, schedules were developed in forty seconds on the IBM 7072. The model does not generate optimum schedules of movements but rather provides a tool which a medium sized corporation can use: 1) to generate schedules in a much faster manner than the present hand system, 2) to test new policies of shipping before implementation, 3) to compare the financial return of different schedules of movement, 4) last but not least to assist the manager in evaluating alternatives of a particular decision.

**WP4.2 Optimization of Integrated Sea-Port Operations,** A. Novaes, *AMTD Litton Industries, Culver City, California.*

Some large corporations, like oil companies, operate their own fleet of ships. The model presented can be used to optimize the operation as a whole, taking into account life cycle costs for the ships as well as the cost of building and maintaining terminal storage facilities. A queuing model is developed in which the input (cargo to be carried) is Poisson distributed and the interdeparture time intervals are Erland distributed. The optimum is attained by means of a random search technique algorithm.

**WP4.3 Transportation Problem Application to Schedule Multi-Commodities with Pre-Determined Priorities using Shortest Path Techniques,** M. Arbabi, and H. M. Horowitz, *International Business Machines, Federal Systems Division, 18100 Frederick Pike, Gaithersburg, Maryland.*

A new concept using the Transportation Problem with internally generated weights (costs) to implicitly represent preferred scheduling of movements through a network will be presented. The actual solution of the Transportation Problem is accomplished using the shortest path logic first presented by Dr. A. J. Hoffman and Dr. H. M. Markowitz and later modified and generalized by Mr. J. J. Lagemann. The structure of the Transportation Problem array enables the simultaneous consideration of a mix of multi-speed vehicles (with any combination of commodity carrying abilities), priority of each movement, shipping availability dates, preferred delivery dates, acceptable early and late delivery boundaries, etc. A significant part of the tableau structure is the incorporation of a permanent fallout row which not only guarantees honoring infinity weights but eliminates the need of initially setting the summation of the row and column input vectors equal. The multicommodity solution is arrived at by an approximation which reduces all movements to one base commodity and then re-converts back to the original commodity after scheduling. The discussion will be supported by the successful results obtained from an actual computer program based on the method described.

**WP4.4 Container Provisioning for an Airline Network,** Mehmet Gurel and D. Myles Winbigler, *The Boeing Company, Renton, Washington.*

During the coming years one or more types of large all-cargo aircraft will be introduced into commercial airline operations. The economics of cargo handling for these aircraft will require containerization of aircraft loads using bulky and expensive containers. Consequently the usage of these containers will create the problem for airline management of determining the optimum number of containers required. Since the cargo flows are directionally imbalanced in a typical commercial airline network, one of the important decision variables of this problem will be how to ship the empty containers from one terminal to another. In this paper the problem is formulated and a method of solution is given. The solution requires information on periodic flight schedules (departure and arrival times), the container-carrying capacity of each flight, full containers on board each flight, and container-handling procedure at each terminal. The use of the model is illustrated with an example.

**WP5.1 *Operations Research in Marketing—A Progress Report,** PHILIP KOTLER, *Northwestern University, Evanston, Illinois.*

The number of bona fide operations research studies in the marketing area is paltry in relation to the vast number that have been undertaken and reported in the manufacturing area. This fixation with manufacturing problems cannot be explained in terms of dollars involved since tens of billions of dollars are spent each year in the marketing and advertising of products. The author contends that it is largely a matter of the profession attending to the more tractable problems. Marketing processes are considerably complex and it is doubted that present mathematical tools are adequate for the mathematical optimization of marketing problems. The scientific study of marketing problems calls for the creation of new mathematical concepts and solution techniques. This paper reviews the half dozen areas where some serious marketing operation research has started. Results are described in case form and the most promising areas of further work are indicated.

**WP5.2 *Allocating Field Sales Efforts by Means of Linear Programming,** ROBERT M. OLSEN, *Assistant Professor, University of Kansas, Lawrence, Kansas.*

• Sales effort allocation models were developed for two sales branches of a property-casualty insurance company. The models maximized the company's short run expected net revenue from its branches, given its current staff of outside representatives and customer billing capacity. The principal hypothesis was that the programming models' solicitation policies would have produced more net revenue than the company's branches actually produced. Also hypothesized was that the models would disclose inter-branch and intra-branch resource misallocations. Considerable attention was given to the company's goals in formulating policy constraints for the models. The models showed that increased emphasis on securing clients in the company's larger revenue-per-client market segments would have increased its net revenue by 12 per cent. Only a 1 per cent improvement in net revenue resulted from allowing reassignments of the representatives between the branches. The conclusion was that the company's inter-branch personnel assignment procedures were adequate even though its market segment solicitation objective was non-optimal. Various sensitivity analyses also were performed. The models appear generalizable to repetitively purchased industrial goods and services having price inelastic demands.

**WP5.3 *Economic Production Theory in Marketing,** KRISTIAN S. PALDA, *Claremont Graduate School, Claremont, California.*

"Advertising, and selling activity generally, will be pursued like any other productive activities, until the expected returns and costs of various media are equated at the margin." (Stigler, *Theory of Price*, 3d ed., p. 200). Economic production theory is applied in deriving optimal allocation of the advertising budget of the firm. Difficulties, due to the cascading character of the decisions and due to measurement problems, appear. Another application of production theory, this time in marketing research, indicates how industry demand analysis can be strengthened by recourse to econometric estimates of industry production functions. The gap between marginal revenue product and marginal factor cost is the relevant tool here.

**WP5.4 *Operations Research in Marketing,** KURT H. SCHAFFIR, *Arthur Andersen & Co., New York, N. Y.*

The construction of a marketing information system for analysis of past performance and simulation of future results will be illustrated by reference to deal and promotion management in the marketing of consumer non-durables. Actionable information is developed as a basis for short-term marketing programs and long-term policy.

**WP5.5 *A Model for New Product Selection,** GLEN L. URBAN, *The Alfred P. Sloan School of Management, Massachusetts Institute of Technology.*

The problem of selecting one or more new products from a group of potential new products can be approached by the use of a two stage mathematical model. In the first stage, each project is brought to its most profitable position by an optimal specification of the controllable marketing and production variables affecting the product. The best level for each variable can be efficiently determined by an on-line iterative computer search routine. The second stage of the model selects from the potential projects after the uncertainty and potential for additional information have been considered. Since each project may be at a different position in an information network, all projects should be brought to a common information level by an "information discounting." Bayesian analysis is explored as a method of information discounting, but the final selection is based on a balancing of risk against return.

**WP5.6 Simulation Analysis of Product Testing Procedures,** RALPH L. DAY, *Graduate School of Business, Indiana University, Bloomington, Indiana 47401.*

Many difficulties are encountered in evaluating customer reactions to alternative product forms through field tests of product samples. Nevertheless, product use tests are still regarded as a most important information source. Many of these difficulties can be attributed to the lack of models of choice behavior which provide useful guides in the design and evaluation of product tests. A previously reported model which relates test results to a distribution of preferences for a single attribute has been extended to accomodate multiple attributes. This multidimensional model is incorporated in a computer simulation of behavior in product tests. For a given preference structure, experiments are simulated product tests with various levels on the characteristics. The results can provide useful guides to the design and interpretation of actual tests. When the preference structure is not known, the model can be used in reverse mode to estimate its parameters from actual test data. When extensive testing is not practicable, procedures from Bayesian decision analysis can be applied to obtain management's estimates of the parameters. The results of a limited number of actual tests can be used to revise the priors. These procedures can lead to more efficient methods of product testing.

**TA2 Panel on "Operations Research and Range Management",** CHAIRMAN: DR. R. J. FREEMAN, *General Electric Center for Advanced Studies, Santa Barbara, California.*

The panel will consider the problems associated with the management, operation and planning of ranges which support our national missile and space programs. This concerns the effective utilization of a vast network of facilities, equipment, and people. An environment of constantly changing requirements, advancing technology and increasing complexity of operations contributes considerably to the difficulties of this task. Potential contributions that operations research can make to this important area will be discussed.

**TA3.1 *Systems/Cost Effectiveness Implementation,** JEROME KLION, *Rome Air Development Center, New York.*

The accomplishments of the past few years in system and cost effectiveness will be reviewed. The types of analysis and scope which can be done now are identified as well as those which are expected to be accomplishable in the future. In addition, the steps that are being taken to develop the methodology and the means of implementation will be itemized.

**TA3.2 *Cost Effectiveness Analysis for a Complex Airborne Patrol System,** JOSEPH R. GARAFOLA, *ARINC Research Corporation, Annapolis, Maryland.*

A method for assessing the effectiveness of a multi-aircraft system is described. The system is required to maintain a single aircraft at a patrol station for extended periods with a capability of performing various tasks while at the station. The technique was useful in selecting the most productive of various actions proposed to increase system effectiveness by comparing estimated costs with the expected increase in system effectiveness. A series of system states were described and analyzed and the measure of effectiveness was taken as the integrated capability over the total mission time. The number of useful states was so great and the relationships between them so complex, that a simulation program was used. The techniques are generally applicable to complex systems required to operate for extended periods in at least one of a series of usable system states. The need for more reliable cost estimation procedures became evident and work performed in this area is reviewed.

**TA3.3 *Cost Estimates for the Supersonic Transport,** FRANK B. BROWN, *Operations Research Incorporated, Silver Spring, Maryland.*

During the period when the Supersonic Transport was under contract definition study, it was important to the Government to develop methods for objectively evaluating the relative effectiveness and cost of the Lockheed and Boeing versions of the airframes and the General Electric and Pratt Whitney versions of the engine. A crash study was undertaken to develop Cost Estimating Relations (CER's) for both airframe and engine. Since the design of the Supersonic Transport projects estimates into performance and reliability areas considered to be pushing the state-of-the-art, it was important that CER's be developed in a form suitable for extensive extrapolation. Consequently, the approach followed was to base the

CER's, insofar as possible on the physically causative parameters underlying each cost element. Equations were developed, by subsystem, for the cost of R&D, for investment cost, and cost of operation. The final estimates of costs for the combinations of Lockheed/Boeing airframes with General Electric/Pratt Whitney engines lay within a few percent of the final estimates generated by the participating companies.

### TA3.4 *Application of System Effectiveness Analysis Techniques to an ASW Problem, R. C. ALBERTSON, *Vitro Laboratories, Silver Spring, Maryland.*

The development and application of a system effectiveness model for a complex ASW weapon system is demonstrated. Effectiveness evaluation is demonstrated through the application of principles established by the Weapon System Effectiveness Industry Advisory Committee (WSEIAC) to analytically compare competing system configurations during concept formulation. Special emphasis is placed on model development and demonstration where two computer programs are utilized to determine effectiveness parameters based on a target detection model and a performance model. The detection model is used to determine the probability of detecting, localizing, and classifying a target. The performance model combines the output of detection model with the equipment reliability, maintainability, and capability parameters to determine the total effectiveness (probability of hitting the target). Sensitivity of the effectiveness to target tactics, sensor configurations, and time delays is demonstrated. Results of iterations of both models are presented to indicate the relative effect of availability, dependability, and capability parameters on the effectiveness.

### TA3.5 *Validation of the WSEIAC Recommended Approach on the Titan II ICBM, A. J. MONROE and J. M. SCHWARZBACH, *TRW Systems, Redondo Beach, California.*

Following the completion of the deliberations of the Weapon Systems Effectiveness Industry Advisory Committee (WSEIAC), the Ballistic Systems Division of the Air Force Systems Command sponsored a "validation study" of the methodology that was recommended for predicting system effectiveness. The vehicle chosen for study was the Titan II ICBM which had recently entered the operational phase of its life-cycle. This paper discusses the six figures of merit which were developed, their usefulness and mathematical formulation, and the data problems which were encountered. Additional topics which are discussed include the applicability of the "ADC" concept and the role of system effectiveness analysis in "tieing together" pre-existing piecemeal analyses.

### TA4.1 *An Infinite Horizon Cash Balance Problem with Proportional Costs, GARY D. EPPEN and EUGENE F. FAMA, *University of Chicago, Chicago, Illinois.*

A firm is faced with the problem of deciding how much of its assets it should hold in the form of cash. At discrete points in time, the firm determines its current cash balance and decides what changes if any it should make. It is assumed: (1) that the holding and penalty costs associated with holding cash are proportional to the level of the cash balance, and (2) that the balance is changed by transferring funds in or out of a portfolio of earning assets. The costs associated with such a transfer are assumed to be proportional to the quantity of funds transferred. Between decision points, cash flows in and out of the system are to some extent unpredictable. In the model, the random changes in the cash balance during a period are described by a sequence of independent identically distributed random variables. In this paper, it is established that the optimal policy for an $n$ period problem can be characterized by $(U_n, D_n)$. That is, if $i$ (the cash balance at the beginning of period $n$) is less than $U_n$ it should be increased to $U_n$. Similarly, if $i$ is greater than $D_n$ the cash balance should be reduced to $D_n$. Otherwise no funds should be transferred. Particular emphasis will be placed on the solution to the infinite horizon problem and on establishing the relationship between the solutions to the finite and the infinite horizon problems.

**TA4.2 *Efficient Cash Balance Management and Monetary Impact.** DANIEL ORR, *University of California, San Diego, La Jolla, California.*

Abstract not available.

**TA4.3 *Continuous and Discrete Time Approaches to a Maximization Problem,** L. G. TELSER and R. L. GRAVES, *University of Chicago, Chicago, Illinois.*

This paper deals with a class of economic problems in which a firm seeks a maximum present value of its return over an infinite horizon at a given interest rate. This problem has two versions. In the one of our primary concern a monopolist seeks a present-value-maximizing sales (or price) policy and faces a given demand function such that the quantity demanded at time $t$ depends linearly on past and expected future prices. In the second version a firm determines its stock of capital over time so as to maximize the present value of its net return. We show that there are surprising differences for a given model in discrete and in continuous time. For example, in the monopoly problem a solution exists in continuous time if there is an *upper* limit on the discount rate while in the discrete version a solution exists for all discount rates above a lower limit. This paradoxical result as well as other differences between continuous and discrete time approaches have important economic interpretations in terms of the expectations and treatment of uncertainty implicit in these two approaches. As a result we are able to gain fundamental insights into the economic nature of the problems depending on the apparently unimportant detail as to whether the problem is formulated in continuous or in discrete time.

**TA4.4 *Approximation Methods for Linear Programs with Imprecise Marketing Data,** A. C. WILLIAMS, *Mobil Oil Corporation, Research Department, Central Research Division Laboratory, P. O. Box 1025, Princeton, N. J.*

Linear programs, in the form of activity analysis models, are now widely used as aids in the planning of minimum cost manufacturing operations. Adequate descriptions usually require generalized notions of "activity" and of "commodity," however. For example, nonlinearities in manufacturing units may require a large collection of "activities," while quality and capacity "constraints" may require the introduction of artifical commodities. While the traditional activity analysis model is in terms of fixed supplies and demands, it is clear that more general marketing models could be represented by continuing to generalize the notions of commodity and activity. However, there is a crucial factor to be taken into account, namely that any description of the market will ordinarily be in imprecise, perhaps subjective, terms. It is not our purpose in this paper to discuss methods for improving these descriptions, nor even to enter into normative questions of marketing strategy. We ask only how to use best whatever information we do have about the markets in order to plan manufacturing operations. To do this in an activity analysis model, we must from the beginning recognize the imprecise nature of our marketing information, and not seek an operation plan guaranteed to be optimal for unreliable data. Rather we may seek an operation plan which is near optimal (i.e., which satisfices) for a wide range of possible values of market parameters. Thus, we may solve "approximate" linear programs. We present formulas for giving bounds on the amount by which the profitability of operations based on solutions of such approximate linear programs may fall short of optimal. In each case, the unreliable data are used only in calculating such bounds, but not in the linear program itself. We then show how these may be applied for several marketing situations; e.g., monopoly markets and the case in which demands are described by random variables.

### TA4.5 A Competitive Bidding Model of the Treasury Bill Auction Market,

ARMANDO ORTEGA-REICHERT, *Varian Associates, Palo Alto, California.*

This paper considers auctions in which one seller offers $M$ identical objects to $N$ buyers, who may buy at most one. Three alternative ways of conducting the auction are examined: 1) "Price discrimination", under which successful "sealed bids" are filled at their bid prices; 2) "competitive price" auction, in which all the successful sealed bids are filled at the same price; and 3) "open or progressive" auction, in which bids are freely made and announced until no purchaser wishes to make any further higher bids. Other variants of these auctions are also examined. These auctions are formulated as an $N$-person, non-cooperative, non-zero sum game in which each purchaser has a subjective value or "resale price" for him, and based on this value, he places a bid that maximizes his expected profit. These values are drawn from a common probability distribution. Equilibrium strategies are determined and, assuming that each buyer decides to adopt his optimal strategy, the seller obtains the expected value of the revenue generated by these bids. It is intuitively clear that the buyers will follow a different bidding strategy, depending upon the type of auction, and the seller will choose that auction in which he maximizes his revenue from the bids. From this model, we conclude that the seller obtains the same expected revenue under the three alternative auctions considered.

### TA5.1 A Hospital System Planning Model, DANIEL HOWLAND, *Ohio State University, Columbus, Ohio.*

One of the most difficult problems faced by top level hospital system planners is that of predicting the consequences of their long range decisions for patients. Since the function of hospital systems is to provide patient care, the patient-centered consequences of top level decisions should be predicted if the dangers of suboptimization are to be avoided. In order to provide necessary planning information, a community-to-patient hospital system model is being developed. Starting at the lowest level, i.e., at the bedside, a simulation model is being developed to describe the information-decision network by which information is developed for: (a) the physician at the bedside of the individual patient, (b) the administrator who must deal with aggregates of patients, and is concerned with cost allocations, and (c) the community planning group who deal with aggregates of hospitals. Each group is concerned with a different time frame, but since top level community decisions place constraints on future patient-care capabilities at the bedside, the top level planners must be able to predict the consequences of their decisions. Viewing the entire patient-community system as an adaptive organization, a cybernetic, i.e., information and control, model is being developed to answer the following questions: (a) How do administrative decisions effect the level of decision maker? (b) How do community level decisions effect patient care, and what administrative information is needed by community level planners to predict the consequences of their decisions at the bedside? The research in progress to provide answers to these questions will be described.

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**TA5.2 Some Interesting Problems in Medical Operations Research,** Roger D. Parker, *School of Hygiene and Public Health, The Johns Hopkins University, Baltimore, Md. 21205.*

A different problem area in three types of analytic studies is discussed: (1) securing a sufficient and efficient set of indicators of disease patterns in analytic studies of diagnosis, (2) determining objective functions of performance for cost benefit studies of health care services, (3) determining the method of inputting data in automated medical record systems. The particular indicators used in a differential diagnostic study of liver disease, in a screening study of thyroid activity and in a study of potency violation in the products of drug firms are discussed as examples of the pattern recognition problem of securing "good" indicators. Health problem indices used in program planning, a rank classification health profile for the aged, and an objective function used in measuring the impact of medical aids in a comprehensive care clinic are given as examples of gaging performance in health care services. The question of fixed format versus free English text in computerized medical record systems is considered and the practical problem of card punching versus optical scanning to get the data in is discussed.

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**TA5.3 Regional Management of Tuberculosis,** Charles S. ReVelle, *Center for Environmental Quality Management, Cornell University, Ithaca, New York;* Walter R. Lynn, *Department of Environmental Systems Engineering, Cornell University, Ithaca, New York;* Floyd M. Feldmann, *Department of Public Health, Cornell Medical College, New York, New York.*

The regional management of tuberculosis in developing nations is studied utilizing the tools of systems analysis. A tuberculosis system is visualized, the system being made up of components which are the epidemiological categories that characterize the disease. The interaction of these components determine the future state of the disease. Controls in the form of therapy, vaccinations or prophylaxis may be superimposed on the natural processes, thus altering the future course of the disease. A descriptive mathematical model describing the flows between the various categories can be used to predict the trends both with and without intervention. An optimization model is derived from the descriptive model under the assumption that a program of reduction of active cases has been specified. The optimization model would be used to select the forms of control which achieve the specified reduction program at least cost. Optimization is accomplished via linear programming. The model is general in that the parameters, costs and initial conditions may be varied for different situations. The descriptive mathematical model and the optimization model which determines the most efficient controls are intended to improve decision-making in tuberculosis management.

### TA5.4 Health Manpower: A Theoretical Framework and an Empirical Application, Richard C. Jelinek, *The University of Michigan, Ann Arbor, Michigan.*

This paper consists of two parts. The first part, resulting from Public Health contract #108-66-201(P), presents an analytical framework for the problems of health manpower with a survey of the use of operations research and economics to study problems within this framework. The second part consists of a specific application of the analytical framework with reference to one category of health manpower—that of nursing; and to one aspect of the problem—that of understanding the supply and demand for a professional group. This study utilizes an econometric structure—represented by a system of simultaneous regression equations—to obtain the empirical relationships on the supply and demand for professional nurses. The major endogenous variable in the model is the number of active professional nurses per state (per 1,000 population), whereas the explanatory factors include: nurse salaries, production of nurses, aid to education, characterization of educational and health facilities, demand on health facilities, number of physicians, and characterization of the population. The data used for estimating the parameters of this model are based on national statistics on a state-by-state basis. A discussion of alternative techniques for estimating parameters of such a model—including the two-state least-squares estimation, the limited-information (maximum-likelihood) estimation, and the full-information (maximum-likelihood), etc.—is presented. Some practical implications of the result of this study are discussed.

### TA5.5 The Need for Evaluating the Effects of New Developments on the Planning of Future Health Facilities, William J. Horvath, *Mental Health Research Institute, University of Michigan, Ann Arbor, Michigan.*

A common difficulty in all long range planning is that new developments which may occur during the life of the program are foreseen only dimly, or not at all, at the time the planning is carried out. As a result, the system is not designed to cope with new developments as they occur resulting in a lower overall effectiveness of the program. This is especially true of any buildings and structures which may be erected under the outdated plan since they may have to be abandoned or modified for other uses at considerable economic cost. Examples of outdated structures in the health field are the numerous empty tuberculosis sanitoria which resulted from the development of chemotherapy and consequent outpatient treatment for the disease. Another case in point are the many idle iron-lung machines which have been made superfluous by the development of an effective polio vaccine. The tremendous increase in medical research over the past twenty years guarantees even more sweeping changes in medical practice over the next few decades. The health planner's problem is to take these future developments into account in providing for new facilities. Because of the uncertainties involved in basic research, a two stage planning process is suggested. A preliminary estimate of facility requirements can be obtained by forecasting future disease rates, assuming that medical knowledge remains static and currently used methods of treatment will still be in use. An estimate of the effects of new developments on these requirements can then be obtained by taking into account the current research effort in each disease category. This may be done either by making extreme assumptions as to the success of these programs and thus bracketing the facility requirements, or by obtaining rough probabilities of success from past experience and using these as a statistical basis for modifying the requirements. In addition to the changes brought about by advances in basic medical knowledge, the need for future facilities can be significantly altered by organizational and conceptual changes as well. An example of this is the growing emphasis on removing chronic patients from hospitals and returning them to the community where treatment can continue while the patient readjusts to his more normal environment. The effect of this type of change on facility requirements can also be evaluated using systems analytic methods. Planning in a dynamically changing environment is a challenge but one that must be faced in view of the increased pace of scientific discovery.

**TA6.1 Reneging and Retrials in Queueing Theory: Results and Applications,** PREM S. PURI, *Purdue University, Lafayette, Indiana,* and GIDEON SCHWARZBART, *Management Sciences Staff, Forest Service, U. S. Department of Agriculture, Berkeley, California.*

The finite population of users, $k$ servers, time dependent queueing model with reneging was found suitable to the study of a self-contained, $k$ channels radio communications network. Let $P_{x,y}(t)$ denote the probability that $y(y = 0, 1, 2, \cdots, k)$ channels are busy with $x - y(x \geq y; x = 0, 1, 2, \cdots, N)$ users waiting for service at time $t$. The steady state solutions for $P_{x,y}$ are obtained for the $M/M/k$ queueing process with reneging. The expression for the laplace transform $G^*$ of the probability generating function $G$ of $P_{x,y}(t)$ and an approximate expression for the generating function $G$ for large values of $t$ are obtained. Exact solutions and numerical procedures for the evaluation of $P_{x,y}(t)$ are developed. These procedures are based on the derivation of recursive expression for the laplace transform of $P_{x,y}(t)$. The existence of real roots for the polynomial in the denominator of this expression is discussed together with a computer oriented procedure for their determination. The above model is then extended to the case of reneging with retrials, a model similar to the one studied by Cohen (Philips Telecommunication Review, vol. 18, 1957) but with the important difference that here before reneging a last effort is allowed to enter into communication.

### **TA6.2 Blocking and Delays in $M^{(n)}/M/C$ Bulk Queueing Systems,** I. W. Kabak, *New York University, New York, N. Y.*

The current literature on the subject of queueing systems has included the analytical study of systems with bulk arrivals. Heretofore, all analyses have been concerned with single server systems only. This paper presents results for queueing systems with bulk arrivals; the particular systems are characterized by poisson arrival epochs with $n$ arrivals at each epoch, exponential service times and $c$ servers. The probability of delay for both loss and delay systems are investigated. In addition, the average delay and the delay distribution for first-come-first-served delay systems are presented. Special cases are indicated and numerical aspects of the computation are discussed.

### **TA6.3 Stopping Rules for Queueing Simulations*,** Irwin W. Kabak, *Graduate School of Business Administration, New York University.*

In queueing simulations when either the service times and/or inter-arrival times are exponentially distributed it is possible to obtain independent estimates of the statistic(s) of interest. The statistic(s) pertain to such items as the probability of a request being served immediately or the proportion of requests that are delayed more than, say, $t$ time units. It is demonstrated that a weighted average of the probability of being served immediately is asymptotically unbiased for two simple queueing systems. In addition, it is shown that an unweighted average is biased for one of these systems. Because the estimates are independent the calculation of the variance of the weighted average is simplified. Computational expressions are presented for the calculation of the mean and variance of the estimate of interest. This paper attempts to present only the nucleus of an idea and indicates several areas where research should prove useful.

* Based upon work performed when the author was employed by Bell Telephone Laboratories, Inc., Holmdel, New Jersey.

### **TA6.4 Computer Simulation of Queueing Models,** G. A. Finkler, *Equitable Life, New York, N. Y.*

Computer simulation of queueing models has been gaining rapidly in acceptance during the last five years. The wide spread use of FORTRAN (Formula Translation), which is a higher-level, scientific programming language, has made programs which were originally developed for specific computers easily transferable to a wide variety of other computers. The recent development of two special simulation languages, GPSS and SIMSCRIPT, has brought renewed attention to this area. They are both highly efficient in performing simulation of queuing models. GPSS III (General Purpose Systems Simulator), which is characterized by a unique logic structure that emphasizes the use of block diagrams, was released as late as 1965 by IBM. GPSS III differs from the other programming languages in that it has a rich block dictionary that provides considerable flexibility to the person who is building the queuing model. SIMSCRIPT (Simulation writing), which is somewhat of a cross between both FORTRAN and GPSS, was developed as recently as 1963 by members of the Rand Corporation. It resembles FORTRAN in that it's generally based on that language, yet it also resembles GPSS, in that it concentrates on the status of the system and the events which modify that status. In order to give an illustration of the use of computer simulation of queuing models, two examples are presented. The first one is a FORTRAN IV program for solving single-channel queues. In this example the arrivals have a Poisson distribution with a mean arrival rate of 1.42 customers per hour. The service facility accepts one customer at a time on a first-come-first-served basis. The service time, on the other hand, has a normal distribution. It averages .34 hours per customer with a standard deviation of .08 hours. The second example is a GPSS III program for solving multiple channel queues. In this one the arrivals also have a Poisson distribution but with a mean arrival rate of 1,250 requests per hour. The service facility accepts three requests at a time on a first-come-first-served basis. The service time, unlike the other example, has an Erlang exponential distribution. It averages 816.37 nanoseconds per request with a standard deviation of 534.49 nanoseconds. The complete program and print-out are shown for each example.

### TA6.5 A Heuristic Approach to the Solution of Special Structured Linear Programming Problems, A. Riesco and M. E. Thomas, *University of Florida, Gainesville, Florida.*

In this paper a heuristic method will be proposed for the solution of a special class of linear programming problems which arise in blending operations in the chemical industry. The problems in question have the following characteristics:

a. the costs in the objective function are homogeneous
b. the variables are upper bounded
c. all terms of the requirements vector are zero with the exception of the terms corresponding to the upper bounds of the variables.

The method here presented is an iterative procedure which assumes an initial feasible solution and which proceeds from this starting point by making continuous improvements in the value of the objective function at each iteration. This is accomplished by increasing one of the variables which is not yet at its upper limit. This algorithm differs from the simplex algorithm and its variation in that it does not necessarily move from one basic feasible solution to another. This feature obviates the need for slack or surplus variables which leads to a corresponding reduction in the computer storage required to solve the problem. Computational experience with the method and comparisons with standard LP codes will be discussed. Extensions of this approach to more general type of problems will be studied.

### TA6.6 Balas' and Glover's Algorithm: A comparison, Ashok Rao, *Leeds and Northrup Co., Philadelphia, Pennsylvania.*

A brief description of the algorithms proposed by Balas and Glover as formulated for implementation on the computer. The computer used is the IBM 360/30. Problems ranging in size from 14 to 125 variables are executed by both algorithms. The discussion includes information on the types of problems used, and a comparison of the execution times. Also compared are the execution times resulting from using an upper bound on the objective function as a constraint. Future avenues for research that may be undertaken are proposed in this paper.

**TA6.7 A Max-flow Algorithm for the Design of Reliable Redundant Electronic Networks,** PAUL A. JENSEN, *The University of Texas, Mechanical Engineering Department, Austin, Texas.*

This paper deals with the problem of designing an electronic digital network using multiple-line redundancy. This type of redundancy uses three replicas of all circuits. To correct errors, and hence increase reliability, majority vote circuits are placed throughout the redundant network. The design problem is to find the optimum distribution of these majority vote circuits. In this paper, the problem is transformed into finding an optimum set of proper cuts of the graph which is the schematic of the network. The population of proper cuts from which the optimum set is chosen is generated by $n - 1$ applications of a max-flow min-cut algorithm. Here $n$ is the number of nodes in the graph. The cut generation procedure is similar to that developed by Gomery and Hu in their research on multi-terminal network flows, except that the procedure is applied to a directed graph. The optimum set of cuts is chosen from the population using a dynamic programming algorithm. The research of this paper solves a problem which has never before been solved for networks with arbitrary topology. The algorithm suggested has been programmed and is computationally feasible for problems of realistic size.

**TP2.1 * Approximations in Some Existing Confidence Interval Estimates of System Reliability,** W. M. WOODS, *Naval Postgraduate School, Monterey, California.*

This paper deals with some of the approximations that are present in some of the existing so-called exact confidence interval procedures for system reliability. Attention is given to approximations in the areas of independence, level of confidence, underlying distributions, and the algebra of reliability. Some numerical evaluations of the effect of the independence assumption are provided for the exponential and normal distributions. Numerical evaluations are given that allow assessments of the assumption of constant failure rate when this is not the case. Some approximate confidence interval procedures are discussed and evaluated from an accuracy point of view.

**TP2.2 * On Confidence Limits for the Performance of a System When Few Failures are Encountered,** S. C. SAUNDERS, *Boeing Scientific Laboratories, Seattle, Washington.*

In some situations encountered today the components are so reliable that no failures are observed within the time available for testing. This can pose a problem in data analysis and interpretation. We consider here the problem of determining lower confidence bounds on the reliability of a complex system such as the S1-C when each component is assumed to have an exponential life and different components have different multiplicities within the system. We discuss and compare the confidence limits obtainable from various interpretations of the data and several theories such as asymptotic likelihood ratio, asymptotic maximum likelihood, systems simulation, and the Bayesian method.

**TP2.3 * Reliability Assessment in the Presence of Reliability Growth,** MILTON KAMINS and ALAN J. GROSS, *The RAND Corporation, Santa Monica, California.*

The relatively brief history of rocket vehicle, and particularly ICBM development has caused a rediscovery of one of the better-known features of the fly-fix-fly methods of aircraft development—the systems tend to become more reliable as one gains experience and applies it to design improvement. Since changes in reliability have important implications for those involved in planning, procurement, support, and command, a method for assessing this changing reliability at any given stage or projecting it to near-future time periods should be of considerable use. This paper proposes reliability growth models or patterns which can be fitted to actual experience data (i.e., launch or flight-test results) to discern the quantitative characteristics of the growth within relatively well-defined tolerances. This objective is achieved through definition of appropriate parametric models and subsequent use of maximum likelihood procedures to obtain estimates of the parameters, and hence of the reliability. Several models are studied in detail with regard to their ability to meet sufficient conditions for the existence of maximum likelihood estimators, and it is shown that only two of the models studied yield maximum likelihood estimates which can be used under the most general circumstances. Numerical procedures are developed for obtaining the estimates of the parameters. Further, the variance-covariance matrix of the estimates is used to construct approximate confidence regions. These models are compared with each other and with alternative nonparametric and Bayesian approaches, using simulated data to make the comparisons. These comparisons show that under the conditions set forth in this study, three of the parametric models (not all of which are appropriate for use under all circumstances) are generally superior in their predictive and assessment characteristics to representative nonparametric methods, and also to an applicable Bayesian procedure.

**TP2.4 * Estimation of Failure Rates in Dynamic Reliability,** DAVID RUBINSTEIN, *General Electric Company, Syracuse, New York.*

Often systems are developed by selecting from promising components those that pass specified life test criteria. Unbiased estimates are derived for the failure rate of the system consisting of the selected components. The estimates are functions solely of the life-test data that determined the selection. In addition, the variance of the estimate of the system failure rate is derived and is, in turn, estimated without bias. The methods proposed have general relevance when the same data is to be used for selection of populations and the estimation of parameters of the selected populations.

**TP2.5 * Reliability Demonstration: Methods of Implementation,** D. K. LLOYD, *TRW Systems—Redondo Beach, California.*

This paper describes the statistical and management methods that have been developed for estimating and/or demonstrating the reliability of the various engine systems of the Atlas, Titan, Thor and Minuteman Missiles over the past decade.

It deals with the problems of applying reliability requirements to programs where test firings, specifically for reliability demonstration, were not permitted and the decision as to whether contractual requirements were met had to be based on data from a variety of engine configurations and test results extending from early development tests through production testing. The methods by which the statistical integrity of the data was maintained in spite of the continuously changing and developmental engineering nature of the programs are described.

**TP3.1 * The Ups and Downs of a (GRAIN) Elevator Simulation,** ROBERT A. SEBASTIAN, *Caywood-Schiller, Associates, Chicago, Illinois.*

The operation of a terminal grain elevator at Baton Rouge has been simulated on a digital electronic computer. This simulation is not intended to, nor could it possibly, replace the superintendent at the elevator. Rather, the simulation captures the essence of the operation so that physical changes in the elevator and its overall use may be evaluated. Emphasis is placed on:

1. the real world problem and the reasons for choosing simulation to solve the problem,
2. the difficulties encountered in "tuning" the simulation to the actual operation, and
3. the translation of simulation results to meaningful recommendations.

In other words, the rewards (or ups) and the problems (or downs) of an elevator simulation will be discussed.

**TP3.2 An Application of Simulation to the Evaluation of Alternate Stocking Environments,** G. A. CAHILL and G. SHEFFIELD, *Western Electric Co., Inc., New York, New York.*

This simulation considers the problem of the selection of an optimum stocking environment, i.e., number and location of warehouses, for the stocking of approximately 8,000 separate low value items, having diverse demand characteristics. Due to the expense associated with the collection of detailed data, techniques of probability sampling were applied to limit the number of items involved in the simulation to approximately 400. A year's business for each alternative stocking environment, was simulated, and recommendations made on the basis of the minimum cost alternative. Tests of statistical significance were applied to the results, and assumptions as to cost parameters were subjected to an extensive sensitivity analysis. The basic simulation was performed using a 1410 Cobol program. The statistical analyses were performed with the use of a 1410 Fortran program.

**TP3.3 Prediction by Simulation of the Reliability and Availability of a Ship System at the Precontract Conceptual Stage,** RICHARD E. IRBY, and DAVID A. REID, *The Stanwick Corporation, Arlington, Virginia.*

Customarily, when predicting the reliability and availability of large ships, hull, propulsion and support systems have been treated separately instead of considering all systems together as a operational entity. This paper describes the use of a Monte Carlo simulation to predict the reliability and availability of an overall ship system prior to the contract and design stage. The ship is considered as a redundant, repairable system, and the simulation is made for a "worst case" mission. The only information available dealt with the concept of operation and design constraints. A model of the ship system was developed, and data on existing equipments which could fulfill the functions specified for the ship were used to derive indices of reliability and availability. A mission scenario was developed to exercise the model. The availability simulation predicted the probability of the ship getting underway within a given time. The reliability simulation predicted the probability of the ship completing the mission assuming that all systems were available on first demand.

**TP3.4 A Model for Analyzing Telephone Costs,** D. A. Lewinski, *Bell Telephone Laboratories, Incorporated, Holmdel, N. J.*

As background for solving the problem of predicting "costs" for future anticipated telephones, Bell Laboratories has been analyzing the cost structure of the general purpose telephone. The basic intent, of course, is to develop methods for predicting life-time telephone expenditure sequences. The general underlying models for such sequences are two dimensional stochastic processes: those that are random with respect to the time between the occurrence of expenditures and random with respect to the "transitions" between the various types of expenditures. One particular realization that can be used as a model to generate expenditures for the current general purpose telephone is an eighteen-state semi-Markov process. The various states correspond either to locations where the telephone may be found or to operations (e.g., field repair) which may be performed on the instrument. Estimates have been provided on the average cost of entering each state, as well as on the transition probabilities and holding times associated with each state. Time-varying transition probabilities are used to study obsolescence. In addition to describing the model, we discuss how the model is used to estimate "annual" telephone costs, predict system telephone movement as a function of time, and evaluate the economies of various alternate operating strategies.

**TP3.5 The Use of Simulation in Studying Information Storage and Retrieval Systems,** Richard E. Nance, *Purdue University, Lafayette, Indiana,* and Norman R. Baker, *Purdue University, Lafayette, Indiana.*

This paper considers an information storage and retrieval system as being a subsystem within a total system configuration which includes the users and the funders of the retrieval system. The three components form a closed loop information feedback system which utilizes user feedback concerning the retrieval system's performance. The information feedback from the user affects decisions of both the funding and operation of the retrieval system in the attempt to satisfy user needs within a finite budget allocation. A departmental library at Purdue University serves as an example of a library/user/funder system modeled using industrial dynamics. The results which such an analysis can produce are discussed.

**TP3.7 Simulation Model of a Computer Controlled Automatic Warehouse,** DOUGLAS F. THOMPSON, *Operations Research Department, Finance Staff, Ford Motor Company, Dearborn, Michigan.*

In the design of a computer controlled automatic warehouse, experience with conventional warehouses is usually not sufficient to aid material handling engineers in evaluating the total effectiveness of alternate handling equipment, layouts, or system operating rules. Because of the complex interrelations among the design variables, it is difficult to determine analytically the effect of varying the parameters or the policies. A simulation model has been developed and programmed in SIMSCRIPT for the Philco 212 computer which will provide data for assisting in the design of an automatic warehouse. The model is sufficiently general so that actual warehousing conditions can be simulated readily. A description of the framework of the model will be given, followed by several case studies of the use of the simulator as an adjunct to the traditional methods of warehouse system design. The paper will emphasize the evolution in the design of a warehouse through interpretations of successive simulation trials.

**TP3.8 Scheduling a Multiple Operating Room System: a Simulation Approach,** SHLOMO BARNOON, *Blue Cross of Western Pennsylvania, Pittsburgh, Pennsylvania,* and HARVEY WOLFE, *University of Pittsburgh, Pittsburgh, Pennsylvania.*

Effective utilization of operating rooms in a hospital depends upon the degree of utilization of facilities and personnel. Variations in number and type of operations cause inconsistent utilization. It is assumed that operating room capacity is larger than bed capacity and therefore beds must be reserved prior to operating room scheduling. A simulation program (written in simscript) is used to determine the advantages and disadvantages of various schedules. Input requirements are demand for operating room time by each surgeon, operating times, number of nurses and anesthetists required for each case, and scheduled and actual starting times. Input variables consist of actual data, or they are generated from their probability distributions by the Monte Carlo technique. The simulator assigns operating rooms, anesthetists, and nurses for each case when they are available. Capacity level of personnel and facilities must be pre-set, and is constant for every run. A report of the performance of the system includes idle time and waiting time of facilities and manpower. The report may be obtained at any desired periodic cycle. The simulator was used to test the effectiveness of various schedules for a suite of operating rooms, in an all elective surgery hospital. With minor modification the simulator may describe a general system of operating rooms.

**TP4.1 * Recent Advances in Network Flows,** T. C. Hu, *University of Wisconsin, Madison, Wisconsin.*

The present paper surveys important results in the theory of network flows which are not included in the book "Flows in Networks" by Ford and Fulkerson. The survey is divided into three areas: 1. Shortest paths and minimal cost flows, 2. Multi-terminal flows, 3. Multi-commodity flows.

**TP4.2 * The Relationship Between Network Programming and the Theory of Nonlinear Electrical Networks,** G. J. Minty, *Indiana University, Bloomington, Ind.*

The earliest mention of a connection between network-programming and electrical networks in the literature seems to be "The Application of a Unique Analog Computer to Product Distribution", by C. E. McCarthy and W. C. Elmore, *Journal of the Technical Association of the Pulp and Paper Industry, 43*, pp. 192A–195A (1960). The relationships were further explored and clarified by J. Dennis, M. Iri, and G. Minty, so that they are well understood by specialists in network-programming. This talk will consist of a historical and expository presentation of the relationship for the non-specialist, culminating with the recent discovery that the "regular matroids" of W. T. Tutte are the necessary mathematical context to "round out" *both* network-programming and electrical network theory to perfectly self-dual theories.

**TP4.3 * Multi Commodity Network Flows,** B. Rothschild, *Massachusetts Institute of Technology, Cambridge, Massachusetts,* and A. Whinston, *Purdue University, Lafayette, Indiana.*

The paper will review some recent results on two-commodity flows including computational results. Several reasonable conjectures concerning extensions of these results will be shown to be false. Finally general multi commodity flow results will be presented for special networks.

**TP4.4 * Shortest Route Methods for Finite State Space, Deterministic Dynamic Programming Problems,** Jeremy F. Shapiro *Massachusetts Institute of Technology, Cambridge, Mass.*

A general finite state space, deterministic dynamic programming model with either a finite or infinite planning horizon is viewed as a network optimization problem. Optimal strategies for the model are characterized by optimal (minimal discounted or average cost) paths in the network. Shortest route type algorithms are constructed which find optimal paths of infinite length. Shortest route methods are also exploited in reducing the work of backward iteration in finding optimal paths of finite length. More important, however, is the fact that for finite planning horizons of sufficient length, any optimal immediate decision must also be an immediate decision that is optimal when faced with an infinite horizon. Thus, in the sense of selecting an optimal immediate decision, successive approximation of an optimal infinite horizon strategy by optimal finite horizon strategies exhibits finite convergence. Upper bounds on how long a time horizon is sufficiently long for this convergence to occur are developed. In addition, tests are given for detecting when this convergence of the backward iterative procedure has been effected. Finally, results on the form of optimal paths of any length are given.

**TP5.1** * **Recent Developments in n-Person Game Theory,** W. F. LUCAS, *The RAND Corporation, Santa Monica, California.*

Several models have been proposed for studying $n$-person games. Most of these models are discribed by means of a characteristic function or some generalization of it. This function assigns real numbers to the subsets (coalitions) of the set of $n$ players. These numbers are then used to define a set of realizable payoff vectors, usually called imputations. Some type of preference relation between these imputations is introduced, and it is used to define a "stable" subset of the imputation set which serves as the "solution concept" for the particular model. In the original von Neumann-Morgenstern model (1944) and several later models, these stable sets are called solutions. There are still many unsolved problems concerning solutions, including the outstanding question about whether every classical game has a solution. Some recent developments concerning these problems will be discussed, including, some particular games which illustrate the strange nature of some solutions, and also some generalizations of the classical theory for which solutions do not always exist. Some important developments concerning other models will also be mentioned, in particular the major results in the theory of bargaining sets the and kernel.

**TP5.2** * **Convex Programming and Systems of Elementary Monotonic Relations,** R. T. ROCKAFELLAR, *Department of Mathematics, University of Washington, Seattle, Washington.*

This paper develops an existence and duality theory for a broad class of convex programs with linear constraints. The theory is as elementary as the one for linear programs, except that it involves manipulating convex functions of one variable. It is based on the differential correspondence between such functions and complete increasing curves in $R^2$. There are special applications to the theory of monotone networks.

**TP5.3** * **Generalized Sequential Unconstrained Methods and Duality Results,** ANTHONY V. FIACCO and G. P. MCCORMICK, *Research Analysis Corporation, McLean, Virginia.*

We specify several properties that define a general parameter-dependent auxiliary function associated with the nonlinear programming problem in $E^n$. Assuming little more than continuity of the problem functions, local unconstrained minimization of the auxiliary function for a specified sequence of parameter values yields a sequence whose limit points are local solutions of the problem. If the set of points satisfying a given constraint has a nonempty interior, the constraint can be strictly enforced for all points in the minimizing sequence. This result being established, the connection with optimality and duality conditions is indicated, via the associated Lagrangian of the problem. For the convex problem it is shown that specializations of the general auxiliary function make it possible to generate a sequence of dual-feasible points converging to a dual solution. The results are considerably more general than those obtained in the past for this approach.

**TP5.4 Asymptotic Lagrange Regularity with Weak Constraint Qualification,** K. O. KORTANEK and J. P. EVANS, *Department of Operations Research, Cornell University, Ithaca, N. Y.*

By introducing a weaker type of constraint qualification for consistent differentiable pseudo-concave programming problems, we obtain asymptotic Lagrange regularity conditions from the theory of semi-infinite programming. We impose the constraint qualification that each constraint function possess an interior point, possibly different for different constraint functions. In case the constraint functions are concave differentiable, then asymptotic Lagrange regularity is obtained without any constraint qualification whatever.

**TP6.1 A Generalized Model for the Study of Space Systems Effectiveness,** M. G. BRUNSCHWIG, *Martin Marietta-Denver Division* and NEIL B. HILSEN, *Bendix Corp.-Navigation & Control Div.*

System effectiveness is defined as a measure of expected achievements of the total spacecraft system in performing a mission. The effectiveness model presented here uses a Monte Carlo approach to simulate an actual space mission. A Monte Carlo trial consists of analyzing the mission to determine the effect, on experiments, of failures occurring in experiment or subsystem equipment. The model uses a random number generator to select failure times based on equipment reliabilities. It considers failures in the spacecraft caused by meteoroid punctures, seal leaks, fire, solar flares and astronaut illness. Equipment failures are examined for possible in-flight maintenance. Repairs are scheduled on an experiment or equipment priority basis. The mission is examined chronologically, based on an input schedule of experiment performances. Printouts are made of all failed equipments, lost experiment time, repair time, and aborted missions. The measure of effectiveness is given by the ratio of simulated experiment on-time to scheduled on-time. The achieved reliability of all equipment, experiments and subsystems may also be measured. Many simulations are made to achieve reliable averages for expected mission time and effectiveness. The program is written in Fortran IV.

**TP6.2 A Monte Carlo Approach to the Planning and Analysis of Space Missions,** F. J. MULLIN, *Analytic Research Operation, TRW Systems, Redondo Beach, California.*

Generally speaking there are two statistical methods analysis which are used in the analysis of space missions. They can generally be described as "analytical" and "simulation" methods. Analytical methods trace the propagation of some statistical characteristic of the actual and/or estimated state vectors, such as some probability distribution or covariance matrix, throughout the mission. On the other hand, simulation methods trace the propagation of individual deviations and uncertainties throughout the mission. When the error source deviations and uncertainties are produced by a random number generator and the mission simulation is repeated for many independent cycles to collect statistical samples of results, the technique is called Monte Carlo Simulation. Analytical methods are generally more rapid, when they are applicable. Many space missions, however, are rather complex so that either analytical techniques have not been developed to cover them, or the mathematics would be so complicated that the advantage of speed in computation would be lost. In those cases one resorts to simulation techniques, which are mathematically much more straightforward to implement than analytic techniques. This paper discusses in detail the applicability and usefulness of Monte Carlo simulation techniques in analyzing and planning complex space missions. The analysis under discussion is sometimes referred to as an error analysis or dispersion analysis and is an essential part of the planning phase of any space mission. The results of such an analysis can indicate whether or not mission constraints and/or requirements will be satisfied when various factors which affect these constraints and requirements differ from their ideal values. The same analysis will also assess the effects of these factors and thus provide very valuable planning information. The specifics of performing such an analysis will be fully discussed in this paper. The discussion will include the philosophy underlying the Monte Carlo approach to this analysis as well as a description of a set of very general computer programs which have been used for such an analysis on the Apollo project.

**TP6.3 The Determination of an Optimum Entry Research Vehicle and Program in a Recent Lifting Body Study,** RAY T. SORRELL, *Martin-Marietta Corporation, Baltimore Division,* HARRY GILDEA and DAVID W. MEROW, *Peat, Marwick, Livingston & Co., Washington, D .C.*

In a recent study of manned lifting body entry vehicles, a methodology was established for assigning entry research tasks to a given flight plan in a way to maximize the total value of research accomplished. In the methodology, the value of performing each research task was derived using the Law of Comparative Judgement, information theory, and probability theory. To obtain the maximum total research value, a task assignment model was developed and implemented with Linear Programming techniques. This model has the objective of maximizing the total value of research accomplished. It contains constraint equations which permit consideration of conditions such as research task precedences, concurrences, exclusions and resource sharing. Inputs for this model were prepared with a 7094 computer program developed for this task. The model itself was run with a 7090 Linear Programming Code. In this study, problems with up to fifteen flights and fifty-two research tasks, resulting in an input matrix of 6,005 variables, 350 constraint equations, and 59,326 entries, were easily solved.

**TP6.4 Countdown Decision Aid,** L. R. GUTSTADT, *North American Aviation, Inc. Space Division, 12214 Lakewood Boulevard, Downey, California 90241.*

This paper presents the conceptual development of an information storage, retrieval analysis and display system. The system is usable by launch control center personnel primarily during a countdown. The program has been conceptually derived to aid rapid decision making during a countdown when an anomaly occurs. Historical data are shown leading to a requirements analysis. Operational procedures are discussed and sample outputs are illustrated. Also included will be the developmental aspects connected with the convolution of statistical distributions, cost categories and the derivation of an effectiveness equation.

**TP6.5 Mathematical Model for Aerospace Maintenance,** C. M. Riebl, *North American Aviation, Inc., Space Division. 12214 Lakewood Boulevard GB22, Downey, California 90241.*

This paper presents the results of an effort to develop a generalized digital computer simulation model of a maintenance sub-system (the aggregate of men, equipment, facilities and material) required to support any given aerospace system. Model scope is concerned with both prelaunch activities performed to prepare an aerospace system for launch and post-launch activity performed during the mission. Modeling attention has been focused on producing quantitative information regarding the operation of the maintenance system in response to demands placed on it. It also provides—measure of the maintenance system's efficiency, performance and cost during this operating period.

**TP6.6 Manned Flight Awareness, an Employee Motivation Program for Manrated Space Vehicles,** Mitchell R. Sharpe, *National Aeronautics and Space Administration, Marshall Space Flight Center, Manned Flight Awareness Office, Huntsville, Alabama.*

With the advent of manned spacecraft and space carrier vehicles, new dimensions of reliability and quality had to be attained in the aerospace industry. The National Aeronautics and Space Administration (NASA) developed a special motivation program to fit the needs of this new type of high precision hardware and to change employee attitudes about the nature of their work. The agency's Manned Flight Awareness program is described. Contractor response and means of implementation of the program are discussed, and typical results of it are given. Program material available and NASA assistance to industry are also described as well as the coordination of the program with the Department of Defense's Zero Defects.

**FA2.1 *Defense System Support Cost Analysis as Related to Project PRIME,** J. Jarret, *Planning Research Corporation, Washington, D.C.*

The purpose of this paper is to discuss some recently implemented changes in the Department of Defense's PPB structure and the impact of these changes on the capability of defense system cost analysts to more adequately define the full resource implications of possible courses of action. Specifically, the paper is addressed to Project PRIME and its impact in the aforementioned context. Project PRIME is simply a short title for a series of activities concerned with programming, budgeting and management accounting—as such it is a distinct, identifiable part of the overall Resources Management Systems, but only a part. Project PRIME suggests two key changes in the DOD accounting system. First, Military Personnel costs will be charged to units where the personnel work. Second, all expense items will be associated with the operating appropriations and none with the procurement or construction appropriations. The long-range goal is to charge an organization unit with 100% of the measurable expenses it incurs. *Expenses* are defined as all personnel costs, military as well as civilian; supplies used by the organization, including spare parts and other consumable material and services received from other units within DOD. *Measurable* excludes allocated and prorated costs. The concept of charging all personnel costs to units where the personnel work is basic to the systems analysis effort. The concept of charging all *measurable expenses* to the organization incurring them is, of course, proper. However, the exclusion of allocated and prorated costs reduces severely the usefulness of the PRIME for cost analysis of defense systems. The problem of estimating the relevant resource implications of alternative weapon systems revolves to a significant degree on the capability of the cost analyst to estimate not only the direct costs of such systems but also their impact on the support structures of the service or services involved. The principal point made in this paper is that Project PRIME is a step in the right direction, but it will be of limited usefulness to the systems cost analyst until explicit account is taken of system support costs—those items which do require prorating and allocation.

**FA2.2 * Cost Model Development for Transportation Systems,** P. DIENEMANN, *Resource Management Corporation, Bethesda, Maryland.*

The Office of High Speed Ground Transportation, of the Department of Transportation, is conducting a broad planning study of alternative transportation systems for the Northeast Corridor stretching between Washington, D.C. and Boston. In support of this program a series of cost analysis models are being developed. Because of the scope and nature of the NEC study, the cost analysis activities were categorized by major transportation system elements: vehicle, guideway, routeway, energy system, terminal and support facilities, and communications and control. The cost analysis methodology for each element is formalized into semi-independent cost models. A brief description will be given for each of the cost models. In order to establish the cost-generating elements for each model, the systems were further subdivided into components. By developing the cost-estimating methodology at the component level, total system costs for numerous system proposals and configurations can be prepared quickly and consistently. Interdependences between system components are treated both directly and indirectly in the cost analysis models. In addition to the cost models, an aggregative network model is being developed that establishes a "systems" overview to the NEC cost analysis. Gross network requirements are computed from basic transportation outputs such as: frequency of departure, network size, travel time for various distances, number of stops, etc. The resource requirements and activity rates generated by the network model become inputs to the cost models. Throughout the presentation, special emphasis is given to the tracked aircushion vehicle (TACV) and high speed rail (HSR) transportation alternatives.

**FA2.3 * Cost Analysis of "In Production" Systems,** ARNOLD F. KLICK, *NUS Corporation.*

This paper presents two approaches to estimation of unit costs and total contract costs while systems are still in production status. The first approach is applicable to production runs where a significant quantity (at least 5 units) have been delivered and three or more cost and schedule data points have been firmly documented. The second approach is applicable in earlier phases of a program where few or no complete units have been produced where several schedule and cost data points have been documented. The second approach uses a pro forma technique relating schedules of an analogous program to the cost buildup. These two approaches are based on the development of a mutually compatible set of definitions and require firm schedule data available in PERT Time and Gannt Charts and cost data available in reports such as the NASA Financial Management Reports (NASA Form 533) and the DOD Cost Information Reports (CIR). The methodology presented in this paper has been utilized in analysis of three major development production contracts. Final estimating procedures enable the analyst to work from both gross and initial project cost information in a manner that gives total program costs by input section, fixed and variable elements, and unit costs and provides a dynamic quantitative costing technique useful at almost any stage of the program.

**FA2.4 *Data Problems in Deriving Cost Estimating Relationships for Ship Procurement,** C. Sites, *Resource Management Corporation, Bethesda, Maryland.*

This paper discusses the practical problems of organizing, analyzing, and adjusting data used in the development of estimating relationships for ship procurement.

Cost estimating relationships relate costs to physical characteristics (light ship weight, cubic number etc.), performance characteristics (cruise range, cruise speed, etc.), program characteristics (quantity, flow time to produce, etc.) and other types of characteristics. Therefore the data may be grouped as relating either to the dependent (cost) variable or the independent cost-driving variables. For each group, the problems and procedures associated with collecting, ordering, and comparing data are discussed separately. Concerning the cost data, the following problems had to be addressed:

1. Differences due to temporally separated observation.
2. Differences due to different lot-size procurements.
3. Variable nature of the government furnished versus contractor furnished machinery.
4. Selection of level of aggregation for estimation.
5. Selection of cost categories for estimation.
6. Verification of the accuracy of the data.

Concerning the independent, cost-driving variables, the following problems had to be addressed:

1. Can the characteristics be uniformily defined over a significant number of ship classes?
2. Are the characteristics available in the early planning stages of ship procurement?
3. How can the redundant variables be eliminated?

**FA2.5 Cost Estimating Relationships for Military Helicopter Airframe Procurement,** Mary A. Biagioli, *U. S. Army Aviation Materiel Command, P. O. Box 209, St. Louis, Missouri.*

Multiple regression analysis has been applied to historical data on direct man-hours required to produce helicopter airframes. Since direct labor and related overhead accounts for more than half the cost of a helicopter airframe, a good estimate of this cost factor is essential to the preparation of a reliable Independent Government cost estimate. The spiralling costs of military hardware dictate that future acquisitions be made on the basis of cost-effectiveness studies. If the cost portion can be predicted accurately enough in advance of production, based upon known or required physical characteristics of a weapons system, an enlightened choice could then more likely be made. The equations resulting from the above-mentioned regression analysis are expected to provide an important tool in this regard.

**FA3 Panel on: Operations Research and the Challenge of Conflict in the Last Third of the Century,** THOMAS W. GEORGE, *North Carolina State University, Raleigh, North Carolina.*

The panel will discuss the environment for conflict, the forms of conflict and the resolution of conflict as a challenge to the operations research profession in the last third of the twentieth century, emphasizing about twenty years from now. The professional environment and the qualifications needed by the analyst will be examined in terms of the nature of future problems of conflict and possible methods for analyzing and solving these problems. As background the panel will consider the influence of the increasing interaction within and between social organizations that will be brought about, for example, by the rapid and easy access to information through the proliferation of information systems and by the mobility of people afforded by new means of transportation. The consequences of conflict in this interaction will be considered against the increasing power, penalties and the widespread influence of modern weapons technology. Discussion of an approach to the total problem through systematic analysis and representation of human behavior will be encouraged. The evolution of forms of conflict and their resolution will be examined as a challenge to the operations research profession. Possible directions and limitations in the development of analyses of political and economic systems will be noted, particularly models for such systems and their use in predictive situations. Consideration will be given to regulation and instabilities in organization interactions. Possible changes in the emphasis of demand in the clientele using operations research, from the military to the political and civilian community for example, will be discussed. Possible changes in the education and experience of the analyst, and how these changes may modify the advisory or potential management roles of the analyst, will be considered together with related aspects of the professional climate. The issues for discussion will be viewed from the standpoint of the operations analyst, the economist, the behavioral scientist, the management scientist, the politician and the technologist. A theme paper will be presented first as a guide to the panel session and it will be followed by short responses from each panel member. Participation will then be opened to the audience.

**FA4.1 * Optimal Maintenance Policy and Sale Date of a Machine.** GERALD L. THOMPSON, *Carnegie Institute of Technology, Pittsburgh, Pennsylvania.*

A machine is to be bought, used for productive purposes for a length of time, and then sold. It is possible to do preventive maintenance while the machine is being used, if desired, in order to slow down the degradation of the machine's capability. The value of owning the machine is the sum of the discounted value of its production through time plus the discounted value of the machine when sold. In this paper a modification of a model due to B. Naslund for the problem is discussed. Using Pontryagin's maximum principle, the problem is treated as one of optimal control with the control variables being the use or nonuse of preventive maintenance and the selection of the sale date. It is shown that the optimal maintenance policy is bang-bang, and methods for finding the optimal sale date are determined. Simple examples show the various kinds of solutions that can be obtained with varying assumptions concerning the actual functions used in the model.

**FA4.2 * A Branch-and-Bound Algorithm for Multi-Level Fixed-Charge Problems,** Arnold P. Jones, and Richard M. Soland, *Research Analysis Corporation, McLean, Virginia.*

Multi-level fixed-charge problems are mathematical optimization problems in which the separable portion of the objective function is the sum of piecewise continuous functions of a single variable. This paper describes a branch-and-bound algorithm that will find the global solution to this type of problem. The algorithm has the feature that a good feasible solution is generated at the start. Moreover, at each step of the algorithm an additional feasible solution may be generated for comparison with the best solution found previously.

**FA4.3 * Separable Markovian Decision Problems,** *RAND Corporation, Santa Monica, California.*

Abstract: Contributions to the theory and computation of those Markovian decision problems whose cost and transition structure separates in a manner that is typified by inventory models.

**FA4.4 * An Algorithm for a Class of Dynamic Linear Programs,** R. Glassey *Univ. of California, Berkeley, California.*

We consider linear programs of a special structure that arise in deterministic production planning over several time periods in which the only link between successive periods is an inventory carry over. The model has the following form

$$\begin{aligned}\text{Minimize:}\quad & z = \textstyle\sum c_t x_t \\ \text{Subject to:}\quad & \left.\begin{aligned} A_t x_t + q_{t-1} - q_t &= b_t \\ D_t x_t &= d_t \end{aligned}\right\} \qquad t = 1, 2 \cdot\cdot T\end{aligned}$$

where $qo = 0$. The vector $x_t$ represents the production activities in period $t$ and $q_t$ is the inventory carry over from $t$ to $t + 1$. The proposed algorithm solves a sequence of one-period linear programs in cycles composed of two phases. During the primal phase, the optimal program for period $t$ generates a demand on period $t - 1$, and at the completion of this phase the solutions for each period constitute a primal feasible solution for the $T$ period problem. During a dual cycle, the optimal program for period $t$ generates a proposal for additional inventory to be carried forward which will reduce the costs of operation in period $t + 1$. At the completion of this phase, we have a dual feasible solution to the original $T$-period problem. The difference between primal and dual objective functions can be used as a termination criterion.

### FA4.5 * Geometric Programming: A Unified Duality Theory for Quadratically-constrained Quadratic Programs and $l_p$-constrained $l_p$ Approximation Problems.

ELMOR L. PETERSON, *University of Michigan; Ann Arbor, Michigan.*

The duality theory of geometric programming as formulated, developed, and applied by Duffin, Peterson, and Zener [1] is based on abstract properties shared by certain classical inequalities, such as Cauchy's arithmetic-geometric mean inequality and Holder's inequality. Inequalities with these abstract properties have been termed "geometric inequalities" in Chapter VII of [1]. A new example of a geometric inequality has been uncovered, and this inequality has been used to extend the "refined duality theory" of prototype geometric programming that was developed by Duffin and Peterson [2] and is explained in Chapter VI of [1]. This extended and refined duality theory treats both quadratically-constrained quadratic programs and $l_p$-constrained $l_p$ approximation problems. By a quadratically-constrained quadratic program one means: minimize a positive semi-definite quadratic function, subject to inequality constraints on the same type of function. By an $l_p$-constrained $l_p$ approximation problem one means: minimize the $l_p$ norm of the difference between a fixed vector and a variable linear combination of other fixed vectors, subject to inequality constraints on the same type of function. This work has been done in collaboration with my student Joseph G. Ecker.

[1] Duffin, R. J., Peterson, E. L., Zener, C., Geometric Programming, John Wiley and Sons, Inc., 1967.

[2] Duffin, R. J., and Peterson, E. L., "Duality Theory for Geometric Programming", *SIAM J. Appl. Math.*, Vol. 14, No. 6, November, 1966.

### FA4.6 Use of Geometric Programming to Maximize the Reliability Achieved by Redundancy,

M. MAZUMDAR and A. J. FEDEROWICZ, *Westinghouse Research Laboratories, Pittsburgh, Pennsylvania 15235.*

This paper considers the problem of optimum allocation of redundant elements in a simple series-system (maximizing system reliability subject to several cost constraints). Under the approximation that the components of the redundancy vector can be treated as non-negative continuous variables, the paper formulates this optimization problem as a Geometric Programming problem, describes techniques for obtaining numerical solutions in general and obtains closed form solutions in a special case. The advantages of using Geometric Programming techniques are several. First it gives a readily computable upper bound on the maximum reliability which is obtained on the set of positive integers. Secondly it gives an approximate value for the optimal solution when the redundancy vector is restricted to the set of positive integers. Thirdly it provides a good starting point from which to begin Proschan and Bray's algorithm. Fourthly Geometric Programming permits non-linear cost constraints to be considered. The only restriction which need be imposed is that the cost functions should be capable of being approximated by a posynomial (a generalized polynomial with real exponents and positive coefficients).

**FA5.1 Project Selection Under Cost and Pay-Off Value Uncertainties,** Dr. T. S. Chidambaram, Dr. B. V. Dean and R. R. Palanki

This paper considers a stochastic version of the project selection model where \$C has to be allocated among $n$ technical approaches so that the probability of at least one approach being successfully completed is maximized. The cost of the $i$th approach, $c_i$, is a random variable with distribution function, $\phi_i$, while the probability of success is, in general, a function $P_i(c_i)$ of the cost. A dynamic programming formulation has been given to solve this problem assuming that the budget allocated to one approach cannot be transferred to another. An Algol program using this dynamic programming formulation has been developed. Further, for a wide class of distributions $\phi_i$, an interesting property of the optimal solutions is derived, where partial funding to at most one approach is a characteristic of the optimal solution. Finally, a stochastic version of the project selection model has been developed, which provides for uncertainty values, and a computer program has been developed which solves the project selection under cost and payoff value uncertainties.

**FA5.2 Planning New Manufacturing Operations,** Richard A. Wald, *Research/Development Division, Lockheed Missiles & Company.*

Paper will cover recommended techniques for the evaluation of start-up costs and manufacturing manhour requirements for new fabrication and assembly operations. The use of a multi-disciplinary team to establish initial plant size, output rate, and outside procurement considerations will be discussed. Attention will be given to the use of Stanford Experience Curves to predict per unit costs in terms of direct manufacturing manhours, and the importance of consistency with planned manning levels. Four diagrams will be included to represent hypothetical values on logarithmetic and arithmetic paper. A method of determining initial staffing expense for salaried non-production employees will be illustrated as a simple linear equation, easily solved. As an example, this study might be concerned with the annual production of 10,000 newly-designed portable electric starter units for turbojet aircraft engines.

**FA5.3 Discrete Dynamic Programming and Capital Allocation,** G. L. Nemhauser, Z. Ullman, *The Johns Hopkins University, Baltimore, Maryland.*

Dynamic programming algorithms are developed for optimal capital allocation over time subject to budget constraints. We extend the work of Weingartner, and Weingartner and Ness, by including multileveled projects, borrowing and lending, reinvesting returns, deferrals and project interactions. We are able to handle dynamic programming models with several state variables because the optimal returns are stop functions. Computational experience with a variety of problems is reported.

### FA5.4 Alternative Approaches to the Measurement of Risk, JAMES L. BICKSLER and JAMES McGUIGAN, *Ford Motor Credit Company, Dearborn, Michigan.*

This paper presents an exposition of a number of alternative criteria of risk. It is demonstrated that certain criteria are incompatible with the acts of a rational investor (firm or individual).

### FA5.5 Production Testing Equipment Cost-Optimization, WILLIAM DEWHIRST HERD, *Hughes Aircraft Company, Los Angeles, Calif.*

The use of high-cost test equipment in conjunction with high production rates is becoming more prevalent as space age requirements call for more sophisticated systems and components. Rising cost of complex test equipment and high production levels demands more concise equipment inventory estimates. The purpose of this paper is to present such a problem and to demonstrate its solution through the use of a Monte Carlo simulation. The problem involves production testing of costly traveling wave tubes where a production increase made it imperative to acquire new test setups involving tradeoff between the cost of purchasing too many or too few test setups to meet increased production level. Basically, existing test procedure was simulated and the effect of increased production level was observed. Many factors precluded use of a purely analytic approach indicating need for a Monte Carlo simulation, such as: random arrival rates of components to the test setups, random failure of test setups, random failures of components, and random varying rework times of failed components. The output provides effective measures for determining the optimal number of test setups required to meet the increased production level, such as: component waiting time, and monthly output.

### FA5.6 Applications of Game Theory Models in Agriculture, DR. EARL O. HEADY, and R. C. AGRAWAL, *Department of Economics, Iowa State University, Ames, Iowa.*

The five most important principles of choice in game theory models have been applied to special conditions of agriculture to find out and suggest their suitability to decision maker under different sets of circumstances. The approaches tried are those suggested by Wald, Savage (Regret), Hurwicz (Optimism-Pessimism), Laplace (Insufficient Reason) and Savage (Subjective Probability). Applications have been made to problems of choice of type of farming, fertilizer and manure use, time of sowing a crop and time of selling the output. Wald's approach is conservative, suitable for a novice, risk-averter or a subsistence farmer having little equity. Laplace's assumption of action under complete ignorance on the part of the farmer is questionable. Hurwicz criterion takes only extremes into consideration and, therefore, not very suitable to agriculture. Assumption regarding farmer's behaviour of minimizing his regret may not be true in practice. No single model is suitable for all situations. The desirability and, therefore, choice of a model is a function of several variables such as goals, psychology, financial condition, education and age of the farmer, variability within the states of nature, type of farming followed, etc.

**FA5.7 A Case Study of Optimizing Production and Inventory Levels,** John Muellner, *Automatic Electric Company, Northlake, Illinois.*

The aim of this study was to achieve maximum possible economy consistent with the objective of satisfying demand, for a given product line. A forecast of annual sales is made by applying a moving Least Squares approach to past data. The results are then broken down into monthly requirements. Inputting this demand into a Linear Programming Model, optimum production and inventory levels are attained for the next twelve month period.

**FA5.8 Forecasting Research Budgets in an Industrial Organization,** Burton V. Dean, Stuart H. Mann, and Burton D. Corwin, *Case Institute of Technology, Cleveland, Ohio*

The problem of estimating industrial research requirements is viewed as a flow of funds model. The transitional flow of funds from a company's operating divisions to its research cost centers is modelled using transfer coefficients that are determined from a statistical analysis of historical data. Transfer coefficients are multiplied by estimated predictions in planned divisional research budgets to yield estimated expenditures in specific research areas. The transfer coefficient model is tested and implementation procedures are presented. Additional work is being done in other organizations.

**FA6.1 The Probability of an Equilibrium Point,** K. Goldberg and A. J. Goldman, *National Bureau of Standards, Washington, D.C.*

Because mixed strategies are inappropriate in certain game-theoretic applications, it is of interest to determine the probability that a "random" non-cooperative game will have an equilibrium-point solution involving only pure strategies. A formula for this probability is derived for the case of two players, and its size is compared with that of the corresponding probability for random zero-sum two-player games.

**FA6.2 Optimization of a Periodic Markov Chain with Return,** E. R. Petersen, *National Energy Board, Ottawa, Canada.*

This paper extends Howard's policy-iteration method to the case of periodic Markov chains. Two different methods which converge monotonically to the optimal policy are presented. In addition, the concept of the one-step transient states is introduced to reduce the dimensionality of this optimization problem and greatly increase the computational efficiency.

**FA6.3 Adaptive Smoothing Using Evolutionary Spectra,** Ambar G. Rao, and Arthur Shapiro, *Operations Research Department, Mobil Oil Corporation, 150 East 42nd Street, New York, N.Y. 10017.*

The importance of adaptive and exponentially smoothed forecasting has led to the development of several schemes using the tracking signal or the smoothed auto-correlation function for changing the value of the smoothing coefficient. An alternative scheme, using evolutionary spectra is proposed. This is likely to be better than the other schemes proposed due to the greater stability and smaller variance of the spectral estimates The smoothing constant is determined by the high frequency component of the spectrum. Use of the high frequency components in an evolutionary fashion leads to a mechanism for adaptively changing the smoothing coefficient.

**FA6.4 Integer Cutting-Stock Problems,** CURTIS J. TOMPKINS, *Department of Industrial Engineering, Virginia Polytechnic Institute, Blacksburg, Virginia 24060.*

A reliable procedure for solving integer cutting-stock problems is presented. This procedure combines the basic features of the knapsack algorithm by Gilmore and Gomory and the additive algorithm by Egon Balas. Appropriate cutting patterns are generated by the Gilmore-Gomory knapsack approach and the resulting linear program is solved through decomposition techniques. If the solution is all-integer the problem is finished; if the solution contains some non-integer values, discrete alternative bounding procedures are employed to formulate a zero-one integer problem. An additive algorithm similar to those of Balas and Glover is applied to this problem and the resultant optimal integer answer is converted back into the original cutting patterns. Cutting knife limitations, multiple stock widths, and multiple cutting machine parameters are included. This algorithm is applied to a real world paper cutting process. Some advantages of the proposed algorithm are: (1) no round-off error is involved (2) a large number of patterns (variables) can be (implicitly) examined, (3) the computational procedure does not become overly involved and (4) relatively quick convergence to an optimal solution.

**FA6.5 A Stationary Problem for a Multi-Commodity Inventory System with Interacting Set-Up Costs,** B. D. SIVAZLIAN, *University of Florida, Gainesville, Florida.*

The stationary characteristics of a multi-commodity inventory system operating under an assigned replenishment policy are investigated. The analysis is carried first for a two-commodity system, and is then extended to an $n$-commodity system ($n \geq 1$). It is shown that for certain initial policies, the steady state decision rule has a simple dyadic structure, namely: either nothing is ordered or all commodities are ordered simultaneously. The optimization problem reduces to a problem in differential-variational calculus with differential inequality constraints. For a two-commodity system, the operating costs for individual and joint ordering policies are analyzed and compared. The analytical and computational aspects of the problem are also discussed.

**FA6.6 Operations Research Techniques in Purchasing,** S. F. DINERSTEIN, L. R. HAGOOD, *Western Electric Company, 222 Broadway, New York, New York.*

The problem concerns finding an optimum purchase plan for the allocation of resin contracts, which exceed thirty million dollars per year. The bidding format was designed with overlapping price breaks. However, the problem was not solvable by Mathematical Programming techniques because the bids within a minimum-maximum price break constraint were for the total order rather than for an individual product order. The solution techniques were the following: (1) Percents of each product were randomly allocated through a simulated Monte Carlo method; (2) the best plan, irrespective of minimum constraints, was derived. Then the prices were adjusted to meet the minimum-maximum constraints by an "Entrepreneurial" Linear Programming technique. (3) A suggestion was made whereby the Purchasing Department would redesign their bid structure to facilitate Mathematical Programming analysis.

**FP1.1 More on the Discount Rate,** HENRY L. ESKEW, *Planning Research Corporation.*

A simplified way of viewing the "discount rate" question in defense systems analysis is to ask: Given a choice between two equally effective alternatives that will exhibit different cost patterns over time, what criterion of preferredness is to be employed? A generally accepted answer is to select that alternative, the estimates of whose costs have the lower present value. At present there are three principal schools of thought concerning what discount rate should be used in performing the present value calculations. There are those who favor a "high" rate—10% or more; those who propose an "intermiediate" rate—around 5%; and those who either propose no rate or one near zero. This paper argues in support of the intermediate position. The discussion is in two parts. Part I is a review of three papers presented by Broussalian, Niskanen, and Sobin at the 1966 ORSA Meeting in Durham. Particular attention is directed at the assumptions on which the first two are based, leading the authors to substantially different conclusions. Part II develops the rationale for using as the discount rate the economy's rate of real growth. The relationship between this and the government borrowing rate is discussed.

**FP1.2 Academic Planning with Program Budgeting,** PAUL W. HAMELMAN, *West Virginia University, Morgantown, W. Va.*

The literature of the PPB system is dominated by examples of application to multimillion dollar governmental agencies. This paper discusses the system in the setting of a micro-organization, an individual university. There are several technical characteristics of institutions of higher learning that are compatible with the requirements of PPB. These characteristics are uncertainty, multiple goals, end-product discernment, and a high degree of interdependency between separately budgeted academic departments. The PPB format is used to derive extended-time program budgets, with major review and decision points identified.

**FP1.3 Systems Analysis and Cost Effectiveness—A Rehabilitation Program Example,** GORDON K. C. CHEN and STANLEY YOUNG *School of Business Administration, University of Massachusetts, Amherst, Massachusetts.*

Various methods have been employed to rehabilitate prison inmates who are scheduled for parole or release. While different purposes may be aimed for different programs, the ultimate objective is invariably to prevent or reduce recidivision and to promote citizenship and employability. This paper discusses the application of systems analysis and cost-effectiveness techniques for evaluating an experimental rehabilitation project designed to aid youthful parolees by providing them with job training and employment in a business organization which cooperates in the experiment. This paper is concerned with the cost and effectiveness of the experiment in the context of systems analysis.

**FP1.4 State of the Art Survey of Methods of Cost Effectiveness Evaluation,** MRS. MARY A. BIAGIOLI and MAJOR ROGER F. MEISSNER, *U. S. Army Aviation, Materiel Command, St. Louis, Mo.*

An extensive bibliography of industry and government published brochures, pamphlets, studies and reports, gathered in a general state-of-the-art survey as related to Army Aviation, were researched for all references to current and projected methods of cost effectiveness evaluation. The resulting paper is organized in two sections; effectiveness evaluation and cost analysis. Methods used by the various contractors ranged from parametric analysis, using mathematical programming and statistical techniques to evaluation of point designs, to a pragmatic "after-the-fact" effort in response to a customer request. In general, a salutary interest in the subject was apparent throughout industry Further free interchange between industry and the Department of Defense should improve the negotiation climate, since agreement between two enlightened participants is likely to be smoother and more satisfactory to both parties.

**FP1.5 Helicopter Component Interrelationships with Design Parameters,** MICHAEL B. BRYANT, *U. S. Army Aviation Materiel Command, St. Louis, Mo.*

This study investigates helicopter components design parameters for use in government cost analysis Helicopters are stratified by mission into observation, utility and cargo classifications. The study is directed toward an investigation of interrelationships within these groupsing among physical and performance characteristics; for example; life versus disc diameter, horsepower, weight, etc., to determine which of the former are cost sensitive. Data is collected locally from QMR's, QMDO's, MIL STD 451, defense contractors and aeronautical manufacturers planning reports. About 20 data points, primarily Army aircraft, are being considered, approximately evenly distributed among the categories above. Confidence limits are applied relative to acceptance or rejection of the data. Principal techniques utilized are analysis of variance and regression analysis. The unique feature of this work is the stratification approach in the development of costing equations as inputs to cost-effectiveness analysis.

**FP1.6 Weighing for Lot Size in the Learning Curve Exponent Determination,** F. J. DAHLHAUS, *Hdq. U. S. Army Materiel Command, Washington, D C.* and NORMAN SMITH, *U S. Army Aviation Materiel Command, St. Louis, Mo.*

The exponent, or as it is more often discussed, the slope in the log-log representation of the learning curve, is an important parameter in making projections for many purposes. Depending on many factors including: product complexity, data reporting peculiarities, production processes and others, lot sizes may range from 1 upward. In the development of the usual statistical measures, i.e. variance, correlation coefficient, standard error, etc., the traditional sample size entry for the substitutions has been the number of lots. Since a large lot represents considerably more data in terms of the independent variable, the traditional methods of substituting appear to be questionable. The research examines the observed differences in the determination of the slopes for a number of Army helicopter systems based on the previous methods as compared to the weighted lot approach, and applies statistical tests to the comparisons.

**FP2.1 An Analysis of A Decision Making Process,** C. Richard Conger, *HRB-Singer, Inc., PO Box 60, State College, Pennsylvania 16801.*

This paper addresses itself to two main points: the decision making process and an example. A comparison and brief discussion is given on the "Systems" process and the "Business" process in which the basic elements of any decision making process are given as (1) Conjecture, (2) Interpretation, (3) Strategies and Games, (4) Risks, Costs, and Payoffs, and (5) Decision or Indecision. The second point presented is an example of the "systems" process in operation. This is a limited description of a project recently completed by HRB-Singer for the Department of the Army. This project assisted in determining the Army's Reconnaissance and Surveillance aircraft requirements in various situations. In each case alternative aircraft allocations were determined and each alternative represented a capability of providing a percentage of coverage in a specified amount of time. Numerous cost and effectiveness factors were considered and are discussed. In this work considerable emphasis was placed on the use of both probabilistic and deterministic mathematical models. What is significant about this project is the number of alternatives presented to and discussed with the decision maker.

**FP2.2 The Equivalence of Two Objective Functions for Optimal Missile Allocation,** R. Emerson Thomas, *Bell Telephone Laboratories, Whippany, N. J.*

In this paper we consider the allocation of missiles to defend a region from attackers. Two simple criteria for finding optimal defensive strategies are: (1) minimize the expected number of penetrators, and (2) maximize the probability of no penetrators. We discuss attack situations in which the two criteria result in identical defensive missile allocations. The proofs of such equivalence contain exact allocation formulas which are easily computed. We also demonstrate attack situations for which the allocations are different under these two optimality criteria.

**FP2.3 EOM—Oriented Penetration Model, Single Aircraft—Single Radar,** G. A. Fleischer, *University of Southern California, Los Angeles, California,* M. Hersh, *Stevens Institute of Technology, Hoboken, New Jersey,* and D. L. Magnuson, *U. S. Naval Missile Center, Pt. Mugu, California.*

This paper describes a logical/mathematical model of the penetration of a single aircraft equipped with electronic countermeasures (ECM) through a region searched by a single radar. The primary model is essentially event oriented. However, certain of the submodels, which determine the time between events, are time incremented at a rate equal to the scan rate of the radar antennae. The state of the system at any time is described by a five-dimensional state vector indicating:

(1) the region in which the aircraft is located; (2) whether or not the ECM operator has detected the presence of the radar; (3) whether or not jamming (active ECM) has been activated, (4) whether or not the radar operator has detected the presence of the aircraft; and (5) whether or not electronic counter-countermeasures (ECCM) have been activated The times required for the aircraft to arrive at each of the subsequent states are computed and compared so that the next event may be determined. The model described in this paper represents one of several submodels being formulated at the U. S. Naval Missile Center, Pt. Mugu, California, to aid in the test and evaluation of penetration aids for Navy attack aircraft

**FP2.4 Multi-Echelon Stockage Model for Aircraft Spares,** W. M. FAUCETT, L. J. YORK, and R D. GILBERT, *Fort Worth Division of General Dynamics Corp., Fort Worth, Texas.*

A computer program has been developed for determining the stock levels of aircraft spares in a base-depot supply system to minimize expected NORS (Not Operationally Ready, Supply) rate at the operational bases. Item demand is assumed to be compound Poisson with a mean value estimated by a Bayesian procedure. When an item is removed there is a probability that it will be repaired in the base shops. Otherwise, it is sent to the depot for overhaul or if repair is not feasible, a replacement is requisitioned. An algorithm has been developed to approximate the values of the probability states of the number of each type of spares in the repair and resupply pipelines. Using these values the expected number of backorders at base supply and the central depot are computed as a function of inventory levels. - The effect of back-orders at the depot is to introduce delays in the resupply of base stocks, hence reducing the supply effectiveness of base stocks. The optimization procedure is a stage by stage process that continues until a marginal utility cost constraint is satisfied.

**FP2.5 The Contingency Transportation Requirements System (CONTREQS),** CARLTON COMBS, JR., ED HAMMELMAN, and CHARLES SPASARO, *Technical Operations, Incorporated, Arlington, Virginia, U S.A.*

A comphrehensive system for automating the transporation requirements data, for which the U.S. Navy Supply Systems Command (NAVSUP) is responsible, has been designed and is being implemented This system, the Contingency Transportation Requirements System (CONTREQS), assists NAVSUP transportation planners to meet the current needs of the U S. Chief of Naval Operations and the Joint Chiefs of Staff for timely and credible transporation contingency and war planning information. The paper will describe the design specifications for an automated data file and computational system which will meet the current needs of NAVSUP in calculating the transportation requirements for contingency, limited, and general war plans and studies to be placed upon the common user military transportation agencies, Military Airlift Command, Military Sea Transport Service, and Military Traffic Management and Terminal Service. The total system designed in this project will be presented in this paper which will contain a description of system input and output, description of system operations, and description of technical specifications including the composition of files, query language, and recommended computer equipment.

**FP2.6 An Operations Research Approach to The Counterbattery Problem,** LEON SEMBACH, *Combat Operations Research Group, Technical Operations, Incorporated, Alexandria, Virginia.*

This approach proposes a novel application of probability theory to solve the perplexing problem of detecting enemy batteries. A technique is proposed which estimates the enemy artillery order of battle, inventories the position areas available to the enemy, and derives distribution functions to predict the areas occupied. Several lateral, axial and circular distributions are derived on the basis of behaviour patterns dictated by tactical doctrine and materiel characteristics. The distribution curves are correlated to assign a probability of occupancy to each inventoried position area and are updated on receipt of reports of enemy artillery activity. Results are used to direct the collection effort, to employ a more objective analysis of available information, and to measure the effectiveness of the counterbattery program.

**FP2.7 A Dual-State Force Planning Cost and Specification Model,** O. BRYK, J. PHILLIPS and C. ROBERTSON, *Research Analysis Corporation, McLean, Virginia.*

This model is designed to aid force planners and analysts. It computes the estimated variable incremental recurring and nonrecurring costs of force alternatives, as well as their personnel strengths and numbers of aircraft, by applying specified alternative force structures (numbers of elements), to a library of force structure element and associated base data. The model's dual-state capability permits the consideration of forces and their resources in two mutually exclusive states, e.g., peacetime and wartime, a normal and a severe environment or low and high activity levels, as defined by the user. Forces in each state incur recurring costs at rates unique to that state. Conceptually, all alternatives are specified changes (including zero) to a force structure specified in an initial condition in either or both states. The model automatically moves elements of the force structure between states to accomplish specified force alternatives and calculates their strength, cost, activation and deactivation implications. The model does not derive joint or fixed costs but accepts their externally computed values to be included in the totals. The research was sponsored by the Director of Cost Research and Analysis and the Director of Southeast Asia Programs, Office of the Assistant Secretary of Defense (Systmes Analysis).

**FP2.8 A Decision-Theoretic Analysis of the President's Vietnam Problem,** LAWRENCE HARRIS, *New York University, New York, N.Y.*

The complexity of the President's problem on what action to take with respect to Vietnam is well recognized. One might ask, what contribution can a decision-theoretic analysis of this very complex problem make? But is it the complexity of the problem that makes essential a systematic analysis of all aspects of the problem, as opposed to informal decision making. In addition, this problem requires the examination and incorporation of judgments on parts of this problem from many areas of competence as well as the subjective preferences of the President. This paper shall first attempt to structure the problem based on official pronouncements and actions. The paper will then point out what factors the President may wish to consider in the assessment of his subjective preferences and what probabilities need to be estimated. This will lead to the kinds of data that need to be collected around the world on which to form judgments. Finally, the paper shall point out how the very pursuit of a decision-theoretic analysis yields insights into the problem and facilitates group discussion on all aspects leading to a rational, consistent decision by the President.

**FP3.1 O.R. and Computer Emphasis in Curriculum of Leading Schools of Business,** J. DANIEL COUGER, *University of Colorado, Boulder, Colorado.*

Deans of 113 Schools of Business, members of the American Association of Collegiate Schools of Business, were surveyed to determine the extent to which computer technology had been incorporated into the required curriculum. The majority of the 87 respondents had not incorporated these materials, although 97 percent of the respondents felt such coverage should be a curriculum objective. As a result of this survey a research project was undertaken, aimed at establishing guidelines to close the gap between curriculum objectives and accomplishments. Eleven schools with a high degree of quantitative content in the curriculum were selected for the research: Carnegie Institute of Technology, Dartmouth, Florida State, Florida, Harvard, Texas, Tulane, Standord, Pennsylvania, U.C.L.A. and Wisconsin. On-site research, supported by a grant from I.B.M., was conducted in these schools during 1966–67. The computer and O.R. curricula are closely intertwined in these schools and this paper will provide the approaches used to integrate the two.

**FP3.2 O.R. in an International Business Curriculum in Japan,** HERBERT GLAZER, *Socio-Economic Institute, Sophia University, Tokyo, Japan.*

O.R. is taught in Japan at the undergraduate level at a number of universities. Sophia University has recently inaugurated the first M.B.A. program in International Business in Japan, including instruction in O.R. with special emphasis on application to business in Japan and the Far East. Instruction and research are conducted in the English language. Although language is somewhat of a problem, all entering students must pass a Fulbright level English examination modelled on the American Embassy examination in Tokyo. The major problem however in teaching a Western type O.R. course in Japan to Japanese students is not language. It is the lack of training that Japanese undergraduate education provides in the Socratic method. In the social sciences as well as the natural sciences, classic methods of instruction and the traditional Japanese university environment produce a graduate who has had little or no experience in applying what he has learned outside the confines of the context in which he heard or read the material. Problems of teaching O.R. then arise in connection with the student's inability to independently apply O.R. ideas and techniques in situations not described in lectures or assigned reading. This is the core problem of Western type instruction in Japan and can be seen affecting Japanese students in graduate business schools in the U.S.

**FP3.3 Optimal Sequencing of Second Language Instruction: An OR Approach,** CHARLES SCHOTTA, JR., *Department of Economics University of California,* and SARITA G. SCHOTTA, *Department of Linguistics, University of California,* This paper presents an analysis of the optimal sequencing of topics in second language instruction in terms of (1) the goals of the course of instruction (in terms of language proficiency) and (2) the relative effectiveness of present technical teaching methods when applied to different topics (e.g., phonology, syntax, etc.) The relative costs of acquiring proficiency (at some given level) in some particular topic, i.e., phonology, are presented in terms of both theoretical and empirical results in linguistics and psychology. The relevent work here is that of Brown-Bellugi, George Miller, and E. Briere. A range of objectives for a second language program (or particular phases of such a program) is postulated. Then, a minimal cost sequencing plan (with a definition of time units for each topic) is produced which meets the particular objective. This is the optimal sequencing plan. This study focuses on the sequencing rather than on total program costs since the achievement of the particular program goal depends in this type of instruction primarily on the sequencing rather than on intensity of a particular phase. The methodology is illustrated through an example of a program for teaching English as a second language to migrant farm workers in a school district in Northern California. The program results, as measured against a test group using the traditional sequencing, provide striking evidence of the gains to be made from an application of OR to curriculum development.

### FP3.4 A Transportation Model of Racial Desegregation in School Systems,

S. Clarke, *Bureau of Applied Social Research, Columbia University, New York, N.Y.* and J. Surkis, *Univac Div. of Sperry Rand Corp., New York, N.Y.*

The problem of achieving given ethnic compositions in urban schools with minimal student travel time is treated as a multi-product distribution problem. Input to the program package consists of student ethnic distribution (by Census Tract or other small area), location and capacity of schools, desired ethnic composition for each school, and the configuration (with reference to geographical coordinates) of fixed-route transportation lines. A maximum per-student travel time and a maximum walking distance can also be specified. The program package constructs a complete network of Tracts, schools, and transportation lines, and using a variant of the Moore algorithm, determines minimum-time paths from each Tract to each school. The minimal path times plus the input information describe a multi-product distribution problem which is solved using MPS/360, whose output specifies how many students of each racial group shall be assigned from a given Tract to a given school in order to achieve the desired ethnic composition and minimize total student travel time. Brooklyn, New York, as of 1960, is being used as the first test case.

### System for Planning Urban and Social Change,

Donald F. Blumberg, *Philco-Ford Corporation, Fort Washington, Pennsylvania.*

Within the last ten years, increasing attention has been placed on the problems of planning social and physical change in urban communities. This planning process has been severely hampered by both the lack of information and the intrinsic difficulty in quantifying interrelationships in a viable social community. The result is the decisions in this area are generally made on the basis of intuition and "action by committee." The Operations Research and Long Range Planning Activity of the Philco-Ford Corporation has been engaged in developing an advanced information and planning system to support managers and decision-makers involved in planning and implementing urban change and social reform. This system involves a complete consideration of the acquisition of raw data, its processing and manipulation in support of quantitative decision models, and the implementation of decision actions. This system provides the capability to simulate a given community in terms of both physical and social characteristics, to move the characteristics of the community forward in time by considering its natural change as a function of assumed exogenous variables, and to consider the impact of specified government action or external activity on the future of the community in quantitative form. This system can be useful as a quantitative tool to assess alternative plans, and is also valuable in defining required information to support decisions processes. The system described above is now operating for selected communities, and plans are underway to extend the data base for broader use.

### FP3.6 Employment of Operations Research in Hospital Design, P. S. HORWITH, *TRW Systems, Redondo Beach, California.*

Among the most serious problems facing the nation's hospitals is the cost factor. The field of hospital design and operation is fallow ground for the application of Operations Research techniques. Direct cost benefits can result. Some of the reasons hospitals are so costly and inefficient to operate:

a) Hospital design—hospital facilities have rarely been designed as a "system"; thus, the result is a group of unrelated, uncoordinated subsystems—clashing, rather than meshing.
b) Logistics—since Operations Research is not employed in the initial system design, logistics in a hospital is an inefficient and expensive nightmare.
c) Hospital operation—traditional methods are used; advanced systems management techniques are not utilized.

The application of Operations Research *before* architectural plans are conceptualized will be reflected in the ultimate design—and will enable efficient operation and lower costs. This, in turn, would lead to the employment of sophisticated management systems, cost-effectiveness methods, PERT-type techniques, line-of-balance, etc. This Operations Research approach can constitute the missing engineering competence to provide the bridge between the physician's skill, the hospital operator's administration, and the architect's esthetics and design. Not until intensive operations research/systems analysis precedes the design stage will hospitals begin to control their spiraling costs.

### FP3.7 Strategic Planning and Management Information Systems, IRWIN BORIS, *Manager Operations Research Montgomery Ward and Company Chicago, Illinois.*

The term management information systems has been propagated throughout the literature and presented to an enlightened management as a mystic tool which will afford management the opportunity to make rationally based decisions utilizing the totality of data available in the file. In point of fact, there is as yet no generally agreed upon definition of management information systems nor an appreciation of the role operations research must play in the creation of such a system. This paper attempts to define M.I.S. in terms of the questions the system answers and the degree of man machine interface involved. Operations research techniques necessary for the creation of such a system are considered and effective utilization for strategic planning is discussed.

### FP3.8 A Working Plan for Programming and Sustaining Growth of Small Scale Industries Around Calcutta, India, B. P. Banerjee, *Macneill & Barry, Ltd., Calcutta, India.*

Recent surveys indicate that the Power Operated Small Scale Industries in the Calcutta Metropolitan District, now suffering from severe underutilisation, can become as viable and productive as their counterparts in the large scale sector if given proper support.

This paper takes cognisance of the fact that the major weaknesses of the Small Scale industries lie in procurement of raw materials, effecting necessary sales and in their lack of working Capital. Notice is also taken of the existence of a central organisation which can act as a nucleus Framework for making good these weaknesses. The paper thereafter proceeds to draw up a working plan for programming and sustaining growth of Small Scale Industries in the region—using minimisation of factor inputs for requisite or prespecified growth in employment as the criterion.

To this end, a linear Programming model after Garvin et al is developed and solved for determining the input requirements over time of the factors (Labour, raw materials and Capital stocks) as also other supports and assistances necessary (including the volume of finished goods to be marketed) to ensure and sustain a predetermined growth rate in employment. A framework is next suggested for providing the necessary organisation to i) Determine the available factor resources so that the feasibility of desired growth may be tested and the linear programming exercise modified as necessary; ii) Implement the plan.

### FP3.9 Computer Simulations to Assist Rational Resource Allocation in Health Sciences Education, Steven Centner, William Wolfson, John R. Walter and Richard Wilson, *Health Sciences Functional Planning Unit, University of Toronto.*

The Health Sciences at the University of Toronto comprise eight faculties and schools including the Faculty of Medicine and its eight associated teaching hospitals. Expansion and reorganisation of Health Sciences educational programs are continually required to keep pace with increasing community health needs. The Faculty of Medicine, for example, is planning simultaneously to increase its undergraduate enrolment from 175 to 250 students per class and to change its undergraduate curricula from the current 'departmentalised' approach to a 'committee' or 'system teaching' approach. Timely and effective allocation of resources is essential in the development of Health Sciences programs. Heretofore inadequate information and administrative tools have been available to help university administrators achieve this objective. The Health Sciences Functional Planning Unit was established in early 1967 to conceive and develop computer-based simulation models to precisely and explicitly assess the resource implications of alternative plans for expanding and reorganising Health Sciences programs. Four basic models are being developed:

I Undergraduate Education Model
II Specialty Training Teaching—Teaching Hospital Model
III Resource Hours to Resource Unit Conversion Models (Academic Staff, Teaching facilities, Patients and vital supplies)
IV Total Resource Requirement and Dollar Cost Projection Models (Total Staff, Total Space, Total Supplies)

All models simulate resource requirements in considerable detail period by period as far into the future as requested. Models I and II show total requirements in resource hours. Models III and IV convert to resource and dollar units, and extend to show incremental resource requirements. Programs are being written in FORTRAN IV, for use on an IBM 7094 installation at the University. Each model is being programmed in two stages—a basic program to output detailed resource calculations in a condensed format, and an administrative reports program to convert selected basic output to reports suitable for immediate transmittal to Health Sciences administrators. The Paper will describe the philosophy of Health Sciences resource modelling; the conceptual and computer models developed to date; some results and conclusions of case evaluations already reported to Health Sciences administrators; and plans for extending the models for use in other Health Sciences centres and in planning comprehensive community health care.

# *Society Affairs*

## THE ORSA COUNCIL MEETING

The Thirty-first Meeting of the Council of the *Operations Research Society of America* convened on 31 May 1967, in the New York Hilton Hotel, New York, N.Y., with John F. Magee, *President*, presiding, and reconvened after the Business Meeting on 1 June 1967, with President John E. Walsh presiding. The following items from the Council Meeting are reported. (Complete minutes can be obtained from the Secretary of ORSA.)

### FUTURE ORSA MEETINGS

| *No* | *Dates* | *Location* | *Chairman* |
|---|---|---|---|
| 32 | November 1–3, 1967 | Chicago | T. E. Caywood<br>Caywood-Schiller Associates<br>401 North Michigan Avenue<br>Chicago, Illinois 60611 |
| 33 | May 1–3, 1968 | San Francisco | Ernest Koenigsberg<br>Matson Research Corporation<br>215 Market Street<br>San Francisco, Calif. 94105 |
| 34 | November 6–9, 1968 | Philadelphia | Leo Rogin<br>Air Warfare Research Dept.<br>NADC<br>Johnsville, Pennsylvania 18974 |
| 35 | Spring 1969 | Denver | George W. Morgenthaler<br>The Martin Company<br>Box 179<br>Denver, Colorado 80201 |
| 36 | Fall 1969 | New Orleans | |
| 37 | Spring 1970 | Washington, D.C. | |
| 38 | Fall 1970 | Detroit or Ann Arbor | |
| 39 | Spring 1971 | Atlanta | |

MEETINGS COMMITTEE: The Meetings Committee was authorized to arrange one of the above meetings as a joint meeting with the *Systems Science and Cybernetics Group* of the IEEE. The Chairman reported completion of a Meetings Manual.

EDUCATION COMMITTEE. The Chairman reported plans for a lectureship program, and the Council authorized the President and Secretary to submit a proposal to the National Science Foundation for support of this program. The Chairman announced the near completion of a brochure on educational opportunities in the field of Operations Research, and the Council authorized a special edition of the Bulletin for purposes of publishing this report.

PUBLICATIONS COMMITTEE: The Chairman announced that the first issue of ORSA's new journal, *Transportation Science*, has been distributed.

SECTIONS COMMITTEE: Two new sections, the *Space Sciences Section* and the *Health Applications Section*, were established. The Business Manager was directed to revise the billing so as to include a $1.00 charge annually for each technical section to which a member wishes to belong.

AD HOC COMMITTEE ON LONG-RANGE PLANNING: The President was empowered to appoint such a commttee to report at the end of one year on recommended goals and activities of ORSA.

LANCHESTER PRIZE COMMITTEE: The Chairman reported that a medal (incorporating the seal of the Society) had been designed for presentation to winners, to replace the plaque previously awarded with the Lanchester Prize.

MILITARY APPLICATIONS SECTION: The Council authorized the sum of $200 to be awarded by the *Military Applications Section* as a prize for the best 1967 paper on military operations research.

IFORS: The IFORS Representative reported that the Fifth Triennial International Conference on Operations Research will take place in Rome in 1969.

AD HOC COMMITTEE ON CIVIL SERVICE STANDARDS: The President was authorized to appoint such a committee to consider civil service standards for operations research positions.

A.I.A.A.: The Council accepted the invitation of the *American Institute of Aeronautics and Astronautics* to co-sponsor a meeting, to be held in Washington, D.C. on 8–10 January 1968.*

APPOINTMENT OF THE 1967–68 COMMITTEES: The following committee chairmen were appointed by the President:

| | |
|---|---|
| *Membership Committee:* | Kenneth W. Yarnold |
| *Publications Committee:* | James C. Hetrick |
| *Education Committee:* | Jack R. Borsting |
| *Nominating Committee:* | George W. Morgenthaler |
| *Lanchester Prize Committee:* | George Shortley |
| *Meetings Committee:* | Robert N. Braswell |
| *Sections Committee:* | William J. Nemerever |
| *Recognition Committee:* | Leslie C. Edie |
| *Representative to NRC:* | George E. Kimball |
| *Representative to IFORS:* | John F. Magee |
| *Representatives to AAAS:* | Walter E. Cushen, Ellis A. Johnson |
| *Representative to Conference Board of Mathematical Sciences:* | Alexander M. Mood |

NEW MEMBERS: The Membership Committee reported its nominees for full membership in the Society. The following were elected by the Council as new members:

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* Subsequently changed to March, 1968

## *Elected Members at 31st National Meeting*

Alexander, William Bowden
Amara, Roy Charles
Banks, Jerry
Bartow, Philip E.
Bauer, Wolfgang F.
Bhat, U. Narayan
Blinkenberg, Robert Louis
Block, Stanley M.
Bonder, Seth
Braxton, Oliver Francis
Bricker, Jacob Leon
Brown, Newell Henry
Brown, Robert Alexander
Bryk, Oliver
Burnes, Robert F.
Capehart, Melvin Eugene
Chamberlain, Robert Glenn
Cohen, Paul
Cohen, Wallace Morton
Corcoran, William J.
Creed, Henry Pierre
Crowley, Kenneth William
Dailey, Thomas Roland
deGhellinck, Guy T.
Delaney, William W.
Dickison, William Edware
Dockery, Howard L.
Dooley, James Ernest
Dornberg, Maurice
Dorweiler, Vernon Paul
Eisenman, Richard Leo, Major
English, John Morley
Eny, Dr. D. Marc
Etter, Daniel O'Connell, Jr.
Evans, David H.
Evans, John A.
Evers, William Henry
Farber, Joseph
Faulkner, Frank David, Prof.
Feidelman, Lawrence Alan
Finkelstein, Roy P.
Forman, Stephen Bruce
Frye, William Hugh
Gessert, Robert A.
Ghare, Prabhakar Mahadeo
Giadrosich, Donald Louis
Giffin, Walter Charles
Glaser, Joseph
Goldstein, Harvey
Goretsky, M. Edward
Greaney, William Andrew
Greene, Marjorie Jo (Mrs.)
Gross, Hiram Lamar
Hammerschmidt, William Warner
Haney, Dan Gish
Harris, Jack Redver (LCDR USN)
Harris, Lawrence
Harris, Stuart Charles
Hasin, Sidney L.
Hastings, Delbert C.
Heilberg, Ernest
Hemsley, James Ridley
Herd, William Dewhirst
Heyman, Daniel Paul
Hillemeyer, William C.
Hiller, Robert E.
Hinderliter, Richard Glenn
Hinkle, Robert Glenn
Hodges, Richard Ray
Homa, David Michael
Horberg, Arthur
Hughes, James Edison
Hundley, Douglas Vernon
Ichniowski, Francis C. John
Inada, George
Ivanoff, George G.
Jackson, Joe Monroe
Janz, Arthur
Johnson, Ellis Lane
Johnson, Walter Fitch
Kanal, Laveen N.
Karp, Abraham Elton
Kelley, Donald Harris
Kelm, Melvin Kurt
Knappenberger, Herbert Allan
Knight, Francis Samuel

Kolar, Robert Paul
Kolesar, Peter John
Krinos, John Dimitri
Kurtz, Freda W. (Mrs.)
Lastavica, John
Lawler, Eugene Leighton
Leibholz, Stephen Wolfgang
Leibowitz, Stanley
Levin, Oded
Lewandowski, Kendrick John
Lewis, Robert Leonard
Lorck, Horace Christopher
Lutman, Roy Eugene
Maltese, Jasper Giuseppe
Martin, Glenn L.
Mason, George H.
Matheson, James E.
McGrainor, Ronald Lamarr
McNeil, Mary
McRoberts, Keith L.
Mechanic, Harold
Metersky, Morton Lewis
Meyer, John H.
Miller, Jay W.
Moore, James Michael
Morrison, Edmund Dunham
Muehleisen, Dolf Edward
Murphy, Harold Victor
Nathan, Irwin
Nesman, Miles A.
Newman, John Taylor
Norton, David Paul
Olson, Howard Charles
Packer, Arnold Herman
Pajak, Zbigniew Tadeusz
Pitman, George R., Jr.
Ploss, Richard Lord
Rath, Frank Joseph
Reck, Harold Clinton
Redgrave, Michael John
Rhode, Alfred Shimon
Robinson, David F.
Roderburg, Theodor K.
Rodgers, Peter Jay
Romberg, Bernhard W.
Rosen, Stanley Baer
Ross, Donald Hilton
Ross, Martin Sheldon
Sabto, Jacob C. A.
Satterthwaite, Francis George
Schaake, John C., Jr.
Schaefer, George Harold
Schlaefli, John Louis
Schmieman, William A.
Schrady, David Alan
Schroeder, Robert Lewis (Major)
Schruben, Leonard W. (Prof.)
Schultz, Edwin Robert
Schwarman, Richard H.
Serado, John J.
Shuman, Perry Lindsay
Shutler, Maurice Francis
Siegfeldt, Harry Joseph
Silver, Aaron Nathan
Simone, Albert Joseph
Sitkin, Charles Paul
Slager, Catherine Linn
Smith, Lee Herman
Södahl, Lars Olav
Solomon, Sterling Irwin
Spielberg, Kurt
Spoehel, Edwin Henry
Stafford, Bruce Hollen
Stamboulis, Anastasios Peter
Stark, Robert Martin
Stewart, George R.
Stimson, Robert Glen
Sturdevant, C. Victor
Taeuber, Richard Conrad
Theil, Henri
Thomas, Marlin Amos
Thomas, Warren
Thomopoulos, Nick T.
Tinsley, William F.
Todd, Lazarus Houston
Trauth, Charles Arthur, Jr.
Turnbull, Stanley W. A.
Urlovic, William Crimwood
Vanarsdall, David Price
von Falkenhausen, Hasso Werner

WALDRON, STEPHEN
WANG, CHIAO JEN
WATKINS, JAMES MARSHALL
WEBBER, MICHAEL DAVID (LT.)
WEBSTER, L. DUVALL, JR.
WEIL, ROMAN L., JR.
WELLS, HOWARD ALONZO
WERTHEIMER, FRANC
WILKINSON, JOHN W.
WILLIAMS, GENE LEE
WILSON, RALEIGH KING
WISZ, GERALD GEORGE
WOLFORD, LEON ROY
WOLFSTEINER, MARILUISE (MISS)
WOLLASTON, JAMES WILLIAM
WOOD, PAUL MIX
WRIGHT, PAUL HAMBLEN
WYLIE, JACK EDWARD
YAROSS, ALAN DAVID
YATES, EDWARD HERBERT
YOUNG, RICHARD DONALD

ROBERT E. MACHOL
*Secretary*

## PRESIDENT'S MESSAGE

On the occasion of our 15th Annual Meeting, I am pleased to report that the *Operations Research Society* continues to grow in size, influence, and effectiveness. The vitality of the Society is a mark of the growing importance of the profession in the affairs of the country and a tribute to the effort and initiative of the membership.

Present total membership is now approximately 6,000, a twenty percent growth in the last year. In addition, we have about 4,000 nonmember subscriptions to our *Journal*, over a 10% increase. Despite the commitment of substantial funds to underwrite new activities in the past year, the Treasurer's Report in the Bulletin shows that we continue to maintain a healthy cash reserve of slightly over $75,000, approximately the same as a year ago.

The principal unusual event of the past year was the service of the Society as host society for the Fourth International Conference on Operations Research, sponsored by IFORS and held in Cambridge in August of last year. MARTIN ERNST served as Chairman of the Program Committee for the Conference, and WILLIAM MARCUSE assumed responsibility for arrangements. The Conference maintained the tradition of outstanding quality which these conferences have established; 338 delegates were in attendance from 22 countries.

The activities of the geographic and technical sections of the Society continue to grow. An outstanding event is the publication of the first volume of *Transportation Science*, a new journal stimulated by the Transportation Science Section and published under the guidance of the Publications Committee. Subscriptions to this new journal already are approaching 1,000. During the past year, the Sections Committee has also been active in improving liaison with the several geographic sections, encouraging the development of new student sections, and assisting in the planning of new technical sections. The Education Committee has drafted plans, generally approved by the Council, for a Visiting Lectureship Program sponsored by the Society to stimulate and assist operations research programs on university and college campuses. You will be hearing more of this in the months ahead. We look forward to increased joint work by the Sections and Education Committees to encourage the formation and development of new student sections, to build interest in the profession among outstanding men and women on campus.

In the course of the past year, I have come to appreciate more than ever how much the Society depends on the Chairman and members of its several committees and its Representatives to organizations with which we are affiliated. Their work has grown in magnitude and difficulty with the growth of the Society and its program. In many cases their service extends over a period of years. I would like to take this chance to express my appreciation to them and, as a representative of the membership as a whole, the thanks of the Society for their constant, often difficult, and too often unnoticed work.

JOHN F. MAGEE
*President*

## THE GROWTH OF THE SOCIETY

The accompanying table shows the growth in membership and nonmember subscribers to the Society's journal that has occurred during the first fifteen years of the Society's existence (TABLE I).

The figures shown are for May 1 of each year and include all the active members and subscribers as listed in the Society's business office on that date. The number of Members shown for 1952 is the number of persons attending the Founding Meeting; the figures for Members in the early years include the now-abolished Fellows.

In 1959 we observed (see this Bulletin, 7 (1959), page B-127) that the growth of the Society's total membership and of the total circulation of its journal *Operations*

TABLE I

| | Members | Associate Members | Student Associate Members | Total Membership | Subscribers | Total Members and Subscribers |
|---|---|---|---|---|---|---|
| 1952 | 73 | — | — | 73 | — | — |
| 1953 | 354 | 191 | 15 | 560 | 180 | 740 |
| 1954 | 439 | 408 | 45 | 892 | 467 | 1359 |
| 1955 | 452 | 687 | 64 | 1203 | 834 | 2037 |
| 1956 | 526 | 913 | 69 | 1508 | 1159 | 2667 |
| 1957 | 689 | 1216 | 104 | 2009 | 1514 | 3523 |
| 1958 | 832 | 1355 | 143 | 2330 | 1700 | 4030 |
| 1959 | 897 | 1583 | 160 | 2640 | 2002 | 4642 |
| 1960 | 944 | 1792 | 208 | 2944 | 2325 | 5269 |
| 1961 | 1021 | 2020 | 164 | 3205 | 2367 | 5572 |
| 1962 | 1137 | 2255 | 191 | 3583 | 2728 | 6311 |
| 1963 | 1316 | 2343 | 331 | 3990 | 2825 | 6815 |
| 1964 | 1365 | 2413 | 381 | 4159 | 3049 | 7208 |
| 1965 | 1590 | 2615 | 372 | 4577 | 2912 | 7489 |
| 1966 | 1750 | 2887 | 491 | 5128 | 3543 | 8671 |
| 1967 | 1897 | 3503 | 563 | 5963 | 3986 | 9949 |

*Research* had been very nearly linear during its first seven years of existence: If $Y$ is the year minus 1952, $M$ is the number of members, and $S$ is the total of subscribers and members, then the lines of regression $M=363Y+132$ and $S=662Y+66$ described the growth to within 76 members and 52 members and subscribers (except for 1957, when the total error is 147 members and subscribers), respectively

This trend continued during the next seven years of the Society's existence, so that through May 1, 1966 the growth could be described by the lines of regression $M=344Y+182$ and $S=583Y+365$ to within 130 members and 243 members and subscribers (except for 1965, when the error is 455 members and subscribers), respectively.

However, during the 1966-67 year the Society's growth was over double what one would expect from these trends: 835 members and 1272 members and subscribers. If lines of regression are derived for the data including this 1967 point, one obtains $M=357Y+117$ and $S=604Y+253$, but these relations fail to predict the 1967 actual data by 491 members and 636 members and subscribers, even though the other errors are within 242 members and 293 members and subscribers (except for 1965, when the error is 616 members and subscribers).

It will be interesting to see whether the linear trend continues, or whether the 1966–67 experience marks a new pattern of growth for the Society

## AIAA/ORSA FORUM ON SYSTEMS ANALYSIS AND SOCIAL CHANGE

The American Institute of Aeronautics and Astronautics (AIAA) and the Operations Research Society of America (ORSA) are jointly sponsoring a Forum on SYSTEMS ANALYSIS AND SOCIAL CHANGE to be held next March in Washington, D.C. Dr. L. E. Root is Chairman of this meeting (President, Lockheed Missile and Space Company), and Dr. John E. Walsh, President of ORSA (Southern Methodist University), is Vice Chairman.

The Forum is motivated by the widespread national interest that has developed in applying to social problems methods connoted by such terms as "the systems approach," "operations research," "analytical techniques refined in the space and defense programs," etc. The Forum is intended to benefit not only specialists in systems analysis, but also social scientists, managers, and officials at all levels of government who are actually responsible for coping with social problems. Through a review of history and current applications, and a survey of future applications of systems analysis, this Forum will deepen our understanding of the strengths, weaknesses, and "futures" of this analytical tool.

## INSTRUCTIONS FOR CONTRIBUTORS TO THE ORSA BULLETIN

The *News and Announcement Section* of the *Bulletin* carries meeting notices of general interest, personal notes and also miscellaneous items. In general, special courses and seminars offered by commercial organizations are not listed, and University short courses are listed only when they are of special interest. Announcements of new products or equipment development are not listed. Current information reporting activities of foreign Operations Research Societies are particularly welcomed, as well as are reports of ORSA Section and Local Meetings, personal announcements *about ORSA Members,* and other current information which may be considered noteworthy yet unsuitable for publication in OPERATIONS RESEARCH, the Society's Journal.

The closing deadline for inclusion in the *Spring* BULLETIN is January 8th yearly, and for the *Fall* BULLETIN, July 8th yearly; material for the Bulletin should be submitted by these dates to the *Editor,* Gordon J. Crook, Operations Research Division, The Chase Manhattan Bank, 1 Chase Manhattan Plaza, New York, New York 10015. (Publication date for the Spring issue is approximately March 15th and for the Fall issue September 25th.) Notices not received in time for current publication are not used unless they are of historical interest. Authors of Invited and Contributed papers to ORSA Meetings will greatly ease the burden of the *Program Chairman* and the *Bulletin Editor* if they will observe the following rules of presentation and format:

1. The *Bulletin* format for abstracts comprises: (a) the title of the paper (not set in quotation marks); (b) *Author name* (without Mr. or Dr.) and the *Corporation or University name,* plus the *Complete mailing address,* i.e., the street address or division or department name, and with the city and state spelled out in full including the Zip Code. (c) The *Bulletin* policy is to publish one paragraph abstracts and all multiple paragraph abstracts are automatically edited to conform to this style; authors are therefore requested to submit the abstract portion as one paragraph.
2. The title of the paper and the name and address of the author should be submitted as one running paragraph as shown in the Fig. 1. To allow for ease of correction, style and type setting, double spacing should be used by authors for all copy submitted. Do not underline or use all upper case type, or otherwise attempt to style submitted copy. For example: names, addresses, organization or subject title should be typed in upper and lower case format with the exception of acronyms such as ORSA, NATO, PERT, etc, which should be typed in upper case; the titles of books should be underlined, and the title of articles should appear in quotation marks when they fall within the body of a text.
3. Each meeting usually produces worldwide reprint requests for papers; many of which are directed to the *Bulletin Editor.* Such requests will not be forwarded by the *Editor* to the authors, but will be returned to the requester indicating that the request should be sent directly to the author. Should reprints of an article not be available upon request, much correspondence would be saved by making a notation to this effect at the end of each submitted abstract.

Work Conserving Priorities, Ronald R. Jones, Department of Industrial Engineering, University of North Carolina, Chapel Hill, North Carolina 27514.

In certain situations, it is reasonable to assume that priority rules do not affect the time spent in service by any job. For queueing models where this is assumed, the priority rules are said to be work conserving. This concept unifies and simplifies the analysis of a variety of priority queues. This will be demonstrated for the nonpreemptive and preemptive resume M/G/1 cases. Results will also be presented which are valid for G1/G/1 cases or queues.

**Figure 1**

## ORSA VISITING LECTURESHIP PROGRAM

ORSA is initiating a Visiting Lectureship Program for the 1967–68 academic year. The program has the following aims: to stimulate existing operations research courses and programs in universities and colleges which do not at present offer degrees in operations research; to aid and motivate the starting of new operations research courses and curricula; to motivate able students towards careers in operations research; to provide education and information on the nature and scope of operations research, and to provide information and advice to students, student counselors and faculty members on the availability of advanced training in operations research.

Lecturers will not only present formal lectures but will be available to discuss teaching problems and curricula matters with members of the staff, and to advise students on future opportunities in study and employment.

Anyone interested in further information should write:

*Visiting Lectureship Series in Operations Research*
c/o PROFESSOR J. R. BORSTING
*Department of Operations Analysis*
*Naval Postgraduate School*
*Monterey, California 93940*

# *News and Announcements*

## 34th NATIONAL ORSA MEETING

Workshops will predominate at the November 6–8, 1968, meeting in Philadelphia. Suitable workshop subjects include, but are not limited to: specific industries, functional areas, techniques or problems. ORSA members interested in organizing workshops on any topic of sufficient interest to attract ten or more attendees are urged to contact the Program Chairman: SIDNEY W. HESS, *Dept. of Statistics and Operations Research, University of Pennsylvania, Philadelphia, Pa. 19104.*

## SPACE SCIENCES SECTION

CHARTER AND MEMBERSHIP: The Space Sciences Section was granted a charter by the Council of ORSA at its recent meeting in New York (end of May) and is in the process of formation. All members (also AM or SAM) of the Society who are interested in the application of operations research techniques to space problems are invited to join the Section. This can most readily be done by sending your name and address to:

Space Sciences Section of ORSA
℅ General Electric Company
816 State Street—Room 508
P.O. Drawer QQ
Santa Barbara, California 93102

All signers of the "Section Formation Petition" presented to the Council of ORSA as well as those who indicated interest in the Section via questionnaire at the May, 1966 ORSA Meeting in Santa Monica, are considered as already being members of the *Space Sciences Section.*

PROPOSED ACTIVITIES FOR SPACE SCIENCE SECTION:

Develop and keep current a bibliography of existing OR literature on space.
Develop definition and listing of space problems amenable to OR.
Develop definition of further OR technique development needed to solve various space problems.
Hold sessions at ORSA meetings or symposia as the need arises.
Conduct liaison with NASA, COMSAT, Air Force, etc. if need arises.
Award prize for best paper on OR and Space.
Publish newsletter covering items of interest—and permitting members to query their colleagues and ask for information, etc.
Hold joint meetings at National and Section levels with appropriate aerospace societies (AIAA, AAS, SAE aerospace group, etc.).
Solicit "invited" articles on problems in aerospace by leading authorities which suggest need for OR help.

FIRST MEETING—CHICAGO IN NOVEMBER: The next meeting of the Section will take place as part of the *Space Sciences Session* of the Chicago ORSA

Meeting in November. This will present an excellent opportunity for members of the Section to meet and discuss future plans. It is urged that everyone who has an interest in the Section try to attend the Chicago meeting; *Space Sciences Session*, Thursday, 2 November 1967, 9:15 A.M.–11:45 A.M.

NOMINATIONS: The by-laws of the Section have been approved by the Council of ORSA. Following the procedure outlined in the by-laws, the nominating committee has proposed a set of candidates for office. These are listed below:

*Candidate for Chairman* —Raoul J. Freeman
*Candidate for Vice Chairman*—Cordell B. Moore
*Candidate for Secretary* —Martin R. Kinsler
*Candidate for Treasurer* —Joseph Farber
*Candidate for Councilman* —Paul Brock
*Candidate for Councilman* —George W. Morgenthaler
*Candidate for Councilman* —Stanley E. Ross

## HEALTH APPLICATION SECTION

At the New York Meeting of ORSA, John Hall presented a petition for establishment of a Health Application Section signed by over one hundred members. The Council approved formation of the section with the following slate of provisional officers:

*Chairman:*—Charles D. Flagle
*Vice Chairman*—George K. Chacko
*Secretary*—John R. Hall
*Treasurer*—Richard K. C. Hsieh
*Council*—Mark S. Blumberg
*Council*—Daniel Howland
*Council*—William J. Horvath

Those interested in membership in the section should write to:

John R. Hall
*Bureau of Health Manpower, US PHS*
*800 N. Quincy St.*
*Arlington, Virginia 22203*

## WASHINGTON OPERATIONS RESEARCH COUNCIL

Winston Riley III, of Westat Research, becomes *President* of the *Washington Operations Research Council* beginning June, 1967. Joann Langston of Tech/Ops C.O.R.G. was elected *President-elect,* and Howard Berger, Department of Defense, was voted *Secretary.*

Also elected as trustees to the Washington professional society are:

Saul I. Gass, *IBM Corp*
Walter A. Hahn, *Environmental Sciences Services Administration*
Murray Kamrass, *Institute for Defense Analyses*
David S. Stoller, *Office of Education*

Eugene P. Visco, *Tech/Ops,* continues as *Treasurer,* while John G. Honig, *Army Chief of Staff,* serves on the Board of Trustees as *Past-President.* The election results were announced at the Annual Dinner Meeting this week, at which Gen. Maxwell D. Taylor delivered the address.

WORC sponsored its *Second Cost-Effectiveness Symposium* at the Marriott Twin Bridges Motor Hotel from March 13–14, 1967. The theme was "*Analysis for Programming, Planning, and Budgeting.*" It was attended by about 350 persons. The preponderance of the attendees came from outside the aerospace industry which traditionally has dominated the attendance at such symposia. This time most attendees represented state and local governments, foreign governments, non-military federal government, small contractors, or universities. The Symposium indicated that the transfer of cost-effectiveness analyses from the Department of Defense to non-defense agencies is not an easy task. Because the problems are different, new techniques for their solution will have to be developed.

## OPERATIONS ANALYSIS OF EDUCATION

The National Center for Education Statistics, U.S. Office of Education will sponsor a Symposium on Operations Analysis of Education in Washington, D.C. on November 19–22, 1967.

This Symposium will be devoted to an examination of the impact on education and educational research of the concepts and techniques of quantitative analysis such as:

Operations Research
Economics
Use of Computers
Multi-variate Analysis
Systems Analysis
Management Sciences
Program-Planning-Budgeting
Cost/Benefit

By means of papers discussing recent research in education utilizing these techniques and survey papers by educational administrators indicating need for such approaches, it will provide an opportunity:

for those in education, to learn about these concepts and techniques;

for those in industry, consulting, and government, to hear about problems in education where they may be applied, and

for the research community applying these methods to educational problems, to have a forum for interchange of technical information.

Further information may be obtained by writing: DR. STEPHEN C. CLARK, *Program Chairman, Division of Operations Analysis, NCES, U.S. Office of Education, Washington, D.C. 20202.*

## OPERATIONAL RESEARCH SOCIETY

The new address of the *Operational Research Society* is
62 Cannon Street
London E.C. 4
New telephone number is (01) 236–9042.

## FOURTH INTERNATIONAL SYMPOSIUM ON THE THEORY OF TRAFFIC FLOW

The Fourth International Symposium on the Theory of Traffic Flow will be held in Karlsruhe, Germany, in June, 1968. As in the previous meetings, which took place in Detroit, London, and New York, the symposium will serve as an international forum for discussions on the latest research in road traffic. Vehicular traffic flow, optimization of road networks, and economic questions in road transportation will be main topics on the agenda.

Papers on these subjects which must deal with the fundamentals of road traffic science should be sent to:

Lehrstuhl fuer Verkehrswesen
Attn.: Dipl.-Ing. Paul Baron
Technische Hochschule
(7500) Karlsruhe/Germany

by 1st January, 1968, brief abstracts of papers by 15th September, 1967. For further information, please contact the same address.

## WALSH TO VISIT MAJOR OR SOCIETIES

John Walsh, in his role as ORSA President, is planning to visit the major OR societies in the world during his term of office. These visits have the goal of promoting closer relationships among operations researchers of different countries. Visits have already been made to the societies of Australia, Great Britain, Greece, India, Japan, Mexico, New Zealand, and Spain (in July–August, 1967). The societies of Argentina, Belgium, Canada, Denmark, France, Germany, Italy, Netherlands, Norway, Sweden, and Switzerland are to be visited in late 1967 and early 1968.

## SHORTER NOTICES

Affiliate memberships in the Group on Engineering Writing and Speech (G-EWS) of the Institute of Electrical and Electronics Engineers (IEEE) are open to those ORSA members who have not been members of IEEE during the past five years. G-EWS encourages the study, development, improvement, and promotion of the techniques for preparing, organizing for use, processing, editing, collecting, conserving, and disseminating any form of information in the electrical and electronics fields. Dues for affiliate members are currently $7.50 per year. Inquiries should be sent to: *Technical Secretary, Institute of Electrical and Electronics Engineers, III East 41th Street, New York, New York 10017*

The *International Federation for Automatic Control* held a Symposium in Haifa on September 11–14, 1967. The proceedings of the Symposium will be published in February, 1968. Further information may be obtained from: *The Organising Committee, IFAC Haifa Symposium for Automatic Control, Electric Engineering Dept., Technion City, Haifa, Israel.*

The University of Wisconsin will hold a workshop on Computer Aided Plant Layout in Milwaukee on December 4–5, 1967. Additional information may be obtained by contacting *C. L. Brisley, Institute Director, University Extension, The University of Wisconsin—Milwaukee, 600 West Kilbourn Avenue, Milwaukee, Wisconsin 53203.*

Once a year the Research Information Subcommittee of the *American Institute of Industrial Engineers* requests that research sources throughout the world submit abstracts of research performed in the field of Industrial Engineering. Sources from which abstracts have been obtained include universities, industrial organizations, research institutions, and non-profit organizations, including government agencies and professional societies. These research abstracts are published annually in the Journal of Industrial Engineering and provide a valuable service to both industry and universities. Research abstracts are collected in the areas of: WORK MEASUREMENT, METHODS, PLANT ENGINEERING, HUMAN ENGINEERING, ENGINEERING ECONOMICS, ORGANIZATION PLANNING, INDUSTRIAL STATISTICS, PRODUCTION CONTROL, DATA PROCESSING, OPERATIONS RESEARCH, COST ANALYSIS AND INDUSTRIAL ENGINEERING EDUCATION. The subcommittee would appreciate receiving abstracts of any Industrial Engineering research, past and present, which have not been published to date. Standard abstracting forms may be obtained by writing to: Dr. JAY GOLDMAN, Chairman, *Research Information Subcommittee, AIIE, Department of Industrial Engineering, North Carolina State of the University of North Carolina, Raleigh, North Carolina 27607.*

## PERSONAL ITEMS

DOUGLAS L. BROOKS, President of the Travelers Research Center, Inc., Hartford, Connecticut, has been elected to the Board of Directors of DeBell and Richardson, Inc. of Hazardville, Connecticut.

THEODORE S. LEWIS has been promoted Manager of the Computer Applications Section of IIT Research Institute, Chicago, Illinois.

CHARLES F. DAVIS, JR., has joined the Research Division of Raytheon Company, Waltham, Massachusetts.

RICHARD W. GARRETT has joined Eli Lilly and Company, Indianapolis, Indiana.

RALPH F. BAXTER has been appointed Executive Vice President in charge of the Special Products Group, Avery Products Corporation, San Marino, California.

DAVID J. WARREN has been named Assistant Manager of the Operations Research and Systems Department, Esso Mathematics and Systems, Inc., Florham Park, New Jersey.

TAPP S. TAVES has joined the staff of the Dikewood Corporation, Albuquerque, New Mexico, as a Senior Research Engineer.

Operations Research Incorporated (ORI), Silver Spring, Maryland, has announced that the following have joined the staff: ROBERT S. TITCHEN, J. GEORGE CALDWELL, LARRY R. MUENZ, NANCY W. NICHOLES and ALAN I. PENN. HARVEY D. KUSHNER has been appointed Director of Corporate Programs at ORI and HOWARD EISNER has been named Associate Director of ORI's Engineering Analysis Division

CHARLES D. FLAGLE has been given a one year leave of absence from The Johns Hopkins University to serve as Special Assistant to the Surgeon General for Applied Health Technology.

JOHN F. MAGEE, Senior Vice President of Arthur D. Little, Inc., Cambridge, Massachusetts, has been appointed to the National Marketing Advisory Committee of the U.S. Department of Commerce.

DAVID L. ELDREDGE has been appointed manager, operations research for Mead Johnson & Company, Evansville, Indiana.

EVAN T. SHEPARD (Rear Admiral, retired) died on June 7, 1967. Admiral SHEPARD had been Technical Head of Requirements and Operations Analysis in the Information and Environmental Systems Department of the United Aircraft Corporation Systems Center.